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VOL. 3 NO. 1 MARCH, 1916

PROCEEDINGS 36TH YEAR

JOURNAL

OF THE

AMERICAN WATER WORKS ASSOCIATION

PUBLISHED QUARTERLY BY THE

AMERICAN WATER WORKS ASSOCIATION

AT 2419-21 GREENMOUNT AVE., BALTIMORE, MD.

SECRETARY'S OFFICE, 47 STATE ST., TROY, N. Y.

Entered as second class matter April 10, 1914 at the Post Office at Baltimore, Md., under the act of August 24, 1912

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JOURNAL
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JOURNAL

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AMERICAN WATER WORKS ASSOCIATION

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VOL. 3 MARCH, 1916 No. 1

VARIATIONS IN PRECIPITATION AS AFFECTING WATER WORKS ENGINEERING

By Carl Peter Birkinbine

INTRODUCTION

The source of all water supplies, whether surface or underground, is the precipitation of aqueous vapor from the atmosphere; commonly as rain, but also in the frozen forms of snow, sleet and hail. These last are eventually reduced to water and, while their depths are often measured, the recorded quantities are expressed as equivalent water. Part of this precipitation is again evaporated into the atmosphere, other falls directly on the water surface of lakes, swamps or streams, some is transpired by vegetation, a portion runs off directly from the ground surface; the balance entering the soil. Surface waters and streams and the subsoil supply feed the water courses and basins above and below the surface and at various distances from the point of deposition.

All these actions take place in irregular intervals varying in duration, and may be much extended, except that direct or surface runoff is generally limited to brief periods; and the proportions of each vary with the topography, geology, geographical location, character and physical conditions of watershed and its cover, season and climate, which last embraces barometric pressure, temperature, humidity and wind, and with the conditions before, during and after the precipitation.

Water works engineering for domestic supply covers a field of utilization recognized by the courts as the most important application of water supplies and as a primary claim on them. The original source, from wherever taken, is the precipitation, and as this varies there are created different conditions to be met, requiring individual studies.

It is the purpose of this paper to discuss some of these irregularities and extremes, and the requisite provision by which water works engineering meets the conditions, the treatment being general with some instances. It is to be remembered that all examples are specific cases, and while typical of certain "rainfall regions," are to be considered from that view point. Records at some locations may not appear requisite illustrations for studies because of local conditions of development or utilization, but these typify certain rainfall divisions whose precipitations benefit water resources.

Though there is a demand for more climatological data, those available offer such a multitude of interesting examples that any general discussion must limit the number quoted to a few. It is also necessary to omit any detailed exposition of relation between rainfall and runoff, so as not to extend the discussion beyond proper limits.

In compiling data reference was made to our office records, technical literature, published reports and to the various government publications, especially those of the United States Weather Bureau, which has collected by far the greater part of such information. The author expresses appreciation of the courtesies extended by Prof. Charles F. Marvin, Chief of the Weather Bureau, his assistants in charge of the various departments, and by the gentlemen in charge of the various Weather Bureau Stations, and acknowledges the willing assistance of Mr. George S. Bliss, Section Director, and Mr. M. B. Summers, First Assistant, of the Philadelphia office, and Prof. Oliver L. Fassig, in charge of the Baltimore office. Thanks are also offered to his brothers and to associates in the office, for assistance in the compilation of data and review of the manuscript; and acknowledgment of data is also made to the Water Supply Commission of Pennsylvania.

The national scope of this Association suggested that this paper include some of the different precipitations in the United States, which, by virtue of the great area, length of coast, distances between oceans, and the varying topography, experiences a very large range in the quantity and distribution of moisture deposited. Alaska,

the insular possessions, and the Isthmus of Panama, are omitted, although their precipitations are interesting.

Precipitation in Continental United States includes: average annual totals, ranging from approximately 125 inches to 3 inches; individual yearly records varying from 162.5 inches (Glenora, Oregon, 1899) to 0.10 inches (Mohawk, Arizona, 1895);[1] deposition in a single month as high as 41.63 inches (Upper Mattole, California, January, 1888); an individual daily record of 21.4 inches (Alexandria, Louisiana, June 15–16, 1886); even a quantity of 11.5 inches in 1⅓ hours (Campo, California, August 12, 1891).

As of interest are mentioned Cherrapunje, India, which annually receives about 600 inches, mostly in 4 to 6 months, with a record of 905 inches in the year 1861; and Baguio, Philippine Islands, with a 24-hour precipitation (July 14–15, 1911) of 46 inches, measured by an automatic recording gauge.

Water works engineering is herein used in a comprehensive sense to include, not only studies for enlargements or new developments, but also maintenance and operation. To the vagaries of precipitation are ultimately related the requirements of domestic and industrial supply, fire protection and sanitary improvement, the potability of the water, its composition and requisite treatment, the physical features of a system, the methods of obtaining and delivering water, and provisions for disposing of it after use.

PRECIPITATION

Precipitation is a feature of Climatology, but for present purposes the actual occurrence of the deposition of moisture is sufficient.

While it is recognized that much moisture is evaporated from land surfaces and their cover, the rate from exposed water is much higher, and the major portion of this vapor is withdrawn from the oceans, which cover three-fifths of the earth. The Continental United States has, with the included portion of the Great Lakes, only 4 per cent of its area water surface, but is contiguous to two oceans, the Gulf and the Great Lakes. Moisture-bearing winds from the oceans contribute mainly to the precipitation over the States, in amounts varying with topography, distance and meteorological conditions.

[1] Bagdad, California, received no measurable rainfall in the year 1913.

Evaporation, the antithesis of precipitation, is also its major cause, and obviously the two must balance for the earth as a whole, but their local variation is universal.

Plate 1 typifies on a general scale the topographic conditions of our country, and plate 2 indicates the average occurrence of depositions.

Winds, of different classes, play an important part in the condensation of moisture. The city of San Francisco is surrounded by water except on the south, and in summer, when winds from land to sea largely predominate, the average, of 63 years' records, shows that less than 1 per cent of the total precipitation occurred in June, July and August; while if May and September are added, the proportion for the 5 months was but 5½ per cent.

The Middle Atlantic Coast Region, which receives storms from the Lakes, the Gulf and Atlantic coasts and the southeast, as well as thunderstorms, shows a relatively small variation in seasonal averages. Cyclonic circulation is a prime cause of precipitation and the chief agency in its distribution in temperate latitudes.

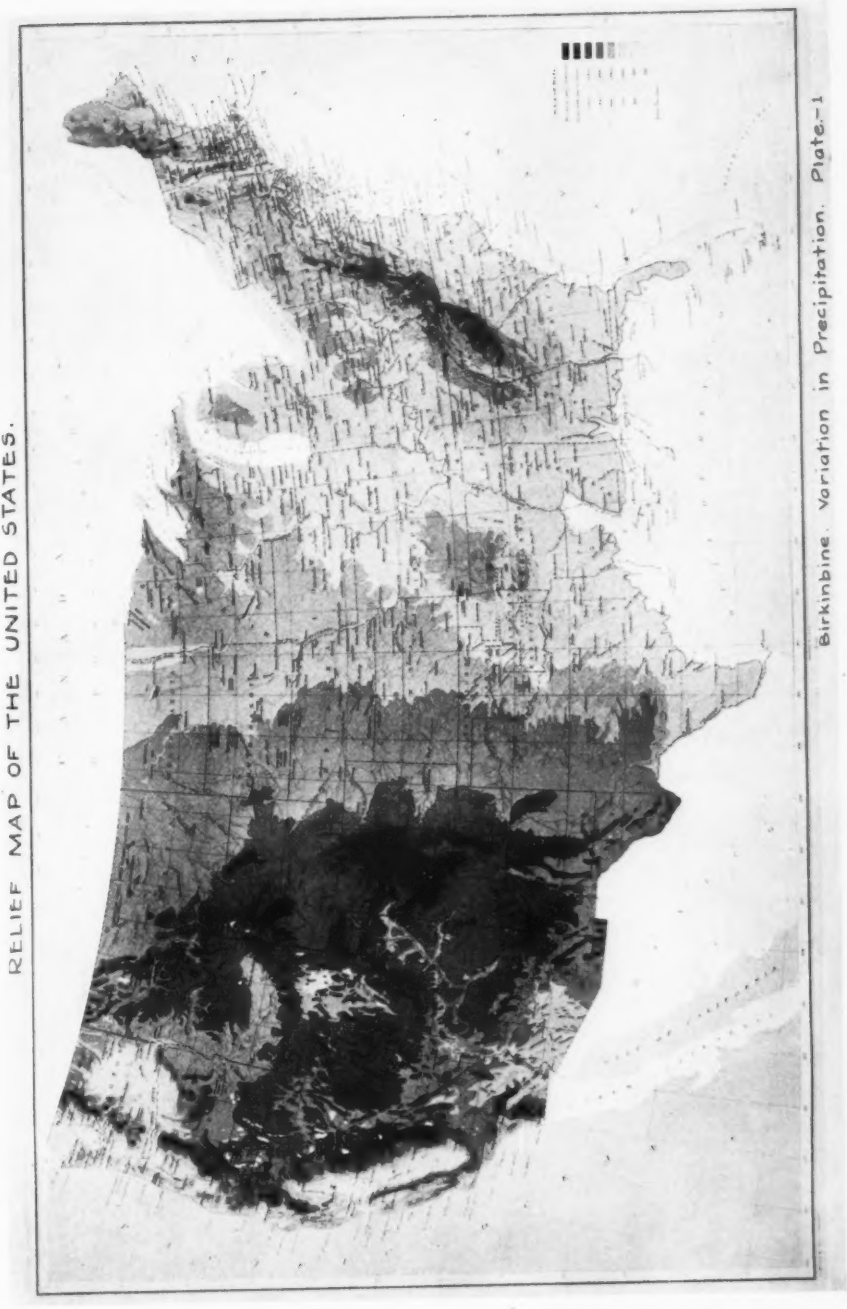
Other variations take place by reason of storm paths. The ocean storms frequently gain in velocity when crossing the land and condense at varying rates as specific conditions occur.

The greater rainfall of warmer latitudes is well illustrated along the Atlantic Coast and Gulf Region, while Southern California demonstrates how wind direction produces deficiency of rainfall in a humid district. (See plates 2 and 32.)

The manner in which elevations in topography create condensation of moisture carried in ocean breezes is illustrated by the higher rainfalls which most of the Alleghenies receive as compared with regions on either side, and by the heavy precipitations which occur on the Cascade and Sierra Nevada ranges; also by the variations in inland states. (See plate 2.)

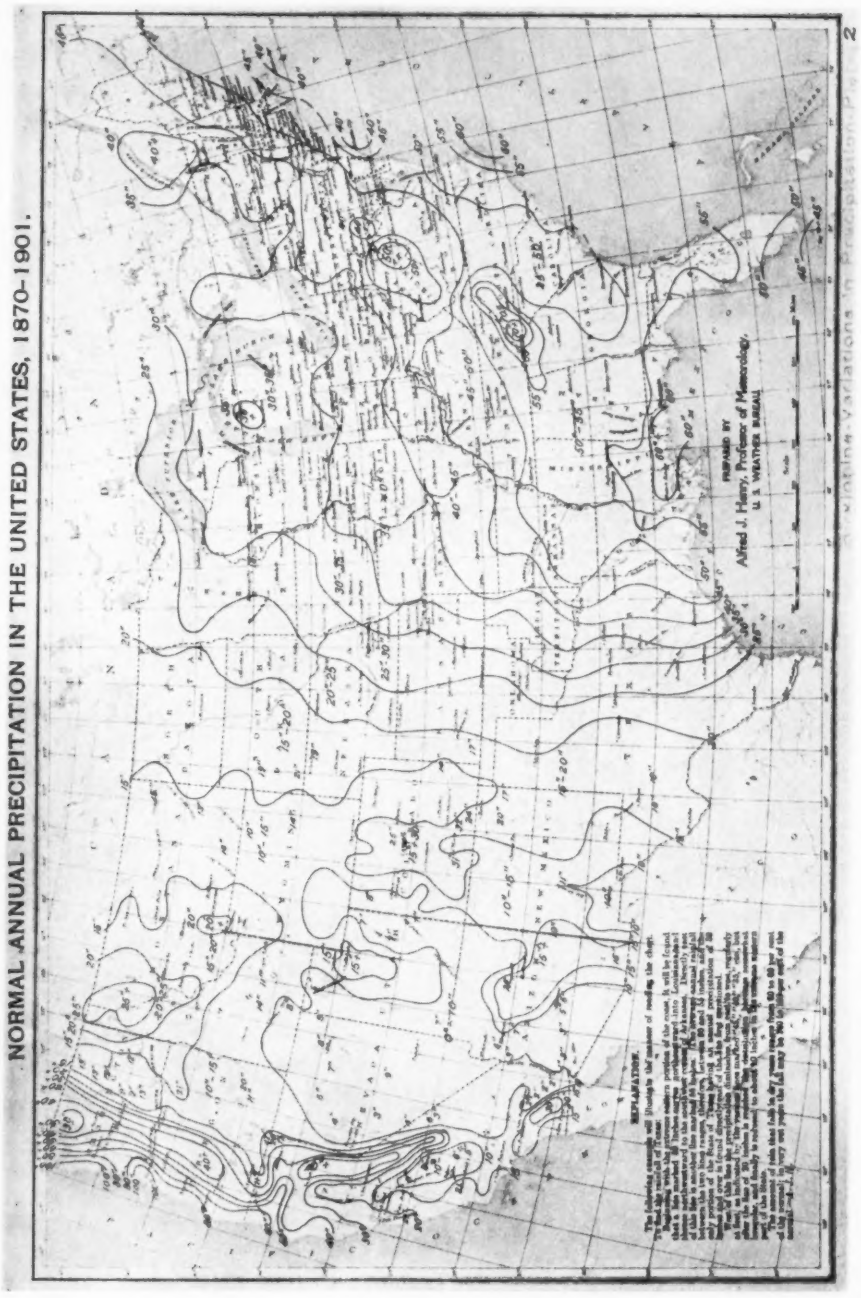
To the water works engineer the most important features of precipitation are its deficiencies and excesses. Long term records are of great service, and will give mean values that represent average conditions for a lengthened interval, and are also valuable as being more likely to indicate ranges in extremes, which are important in considering supply.

Investigation of precipitation records suggests that any records established by actual occurrence may at any time be set aside, but it must be remembered that extreme conditions are of uncommon



RELIEF MAP OF THE UNITED STATES.

Birkinbine. Variation in Precipitation. Plate-1


NORMAL ANNUAL PRECIPITATION IN THE UNITED STATES, 1870-1901.
PREPARED BY
Alfred J. Henry, Professor of Meteorology,
U. S. WEATHER BUREAU.
EXPLANATION.

and irregular occurrence, and that the past two decades have witnessed an enormous increase in precipitation records. The variability of precipitation occurs through periods ranging from extended to brief duration, and in all records the *relative* variation is to be noted. That is, the proportionate amount of any departure from the normal may be more weighty than the actual quantity.

An early recognition of the importance of variations in stream discharge, which is the result of precipitation, is noted in Egyptian history when Amenemhat III, about 2300 B.C., instructed that the height of the Nile be noted on the rocks at the fortress of Semnet, 2nd Cataract, and these engravures are still visible. Other ancient Nilometers are at Memphis and near Cairo, this last having a record of operation of over 1100 years.

Unfortunately there are but few continuous protracted records which show the eccentricities in adjacent periods of various durations.

Extended records may also be totalled into periods of several or a number of years, and plates 34 to 38 illustrate, for specific localities, how the variation in average is reduced as the interval is lengthened. In such averages proper consideration must be given to the effect of extremes, for years of excessive or subnormal quantities in sequence, or in close proximity, will have different effects according to their occurrence in an interval.

Considerable attention has been given by investigators to the reliability proportion of records of various lengths, and the individual annals, the mass curves, and the smoothed curves of averages show that it is important to consider the quantity characteristics of the periods which records cover.

ANNUAL PRECIPITATION

It is recognized that the use of a year in records is not always satisfactory, and a more uniform "water year" is obtained by beginning the 12 months with some date other than January 1, or by dividing the year into hydrologic sections. The data thus obtained are often more suitable for study, though subjected to the varying quantity and distribution of the different portions of the year.

As a unit of comparison the annual precipitation is frequently used, and plate 4 illustrates for specific localities the inconstancies of this quantity, especially to be considered where large storage to cover long periods is required.

Table 1 lists some extremes of the annual precipitation and Table 2 notes the effect of the inconstancies on averages for the year and month.

TABLE 1

Some extremes of annual precipitation and their proportion

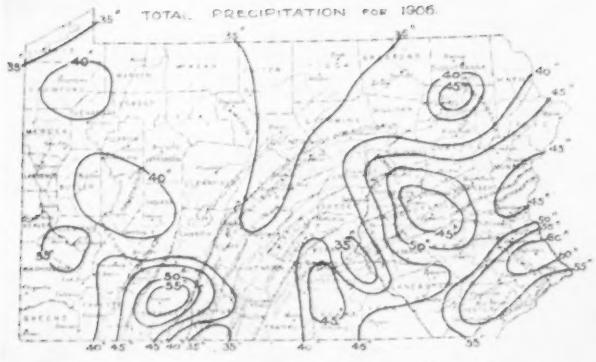
LOCATION	INTERVAL	INCHES OF ANNUAL PRECIPITATION			PER CENT OF MAXIMUM TO MINIMUM
		Average	Maximum	Minimum	
Boise, Idaho	1868–1914	13.81	25.80	6.69	386
Boston, Mass	1818–1914	44.10	67.72	27.20	250
Des Moines, Iowa	1879–1914	32.23	56.81	18.24	311
Detroit, Mich	1871–1914	32.00	47.69	21.06	226
Grand Junction, Colo	1893–1914	8.24	11.61	3.64	320
Little Rock, Ark	1880–1914	49.11	75.54	33.32	230
Los Angeles, Cal	1877–1914	15.71	38.18	5.59	683
Madison, Wis	1869–1914	31.71	52.91	13.49	392
New Orleans, La	1836–1914	56.05	85.73	31.07	276
Omaha, Neb	1871–1914	29.68	48.92	15.49	316
Pueblo, Colo	1889–1914	11.78	18.58	6.14	302
Richmond, Va	1872–1914	41.63	72.02	27.65	260
Rochester, N. Y	1871–1914	33.69	49.89	20.30	245
St. Louis, Mo	1837–1914	39.96	68.83	23.38	294
St. Paul, Minn	1837–1914	27.31	49.69	10.21	486

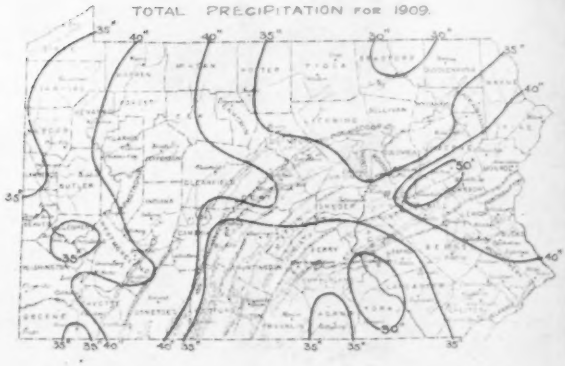
The above are some examples of extremes, and in many districts the proportion between maximum and minimum records covers a smaller range, being included between 150 and 200 per cent. The extreme ratios are limited to certain localities.

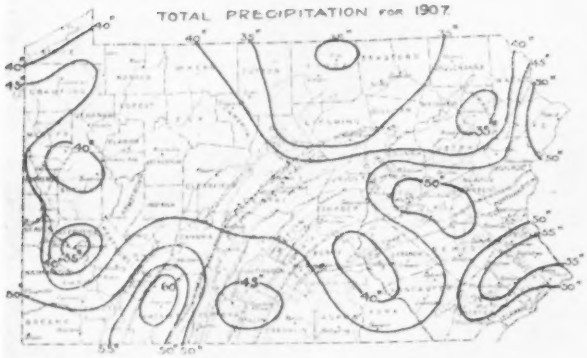
Of importance for certain hydraulic studies is the ratio of minimum to average annual total, which, though varying with the length of record and the characteristics of the period, mainly falls between the proportions of 40 and 60 per cent, there being also certain localities with their special conditions and relations.

The effect of single years and groups of years on even extended averages is illustrated by the following table.

Comparisons of annual depositions are best made when the distributions throughout the year are similar, as the time during which actual precipitation occurs is but a small proportion of the large unit of 8760 hours.


TOTAL PRECIPITATION FOR 1906.


TOTAL PRECIPITATION FOR 1909.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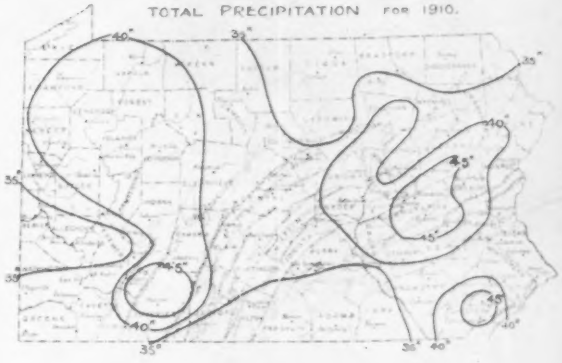
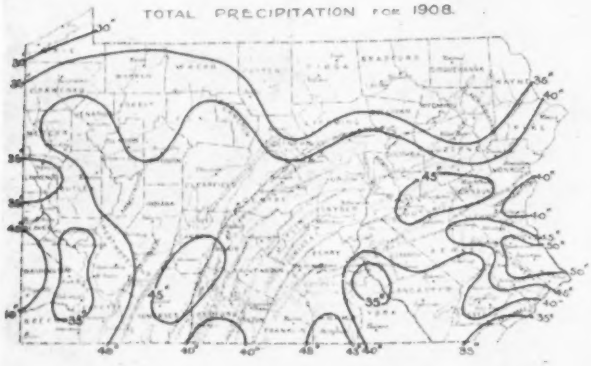
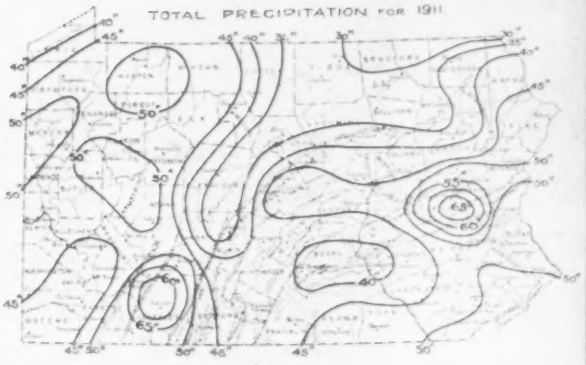
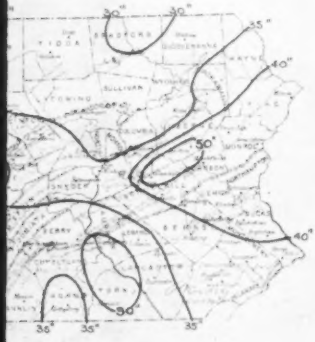

TOTAL PRECIPITATION FOR 1910.


TOTAL PRECIPITATION FOR 1908.

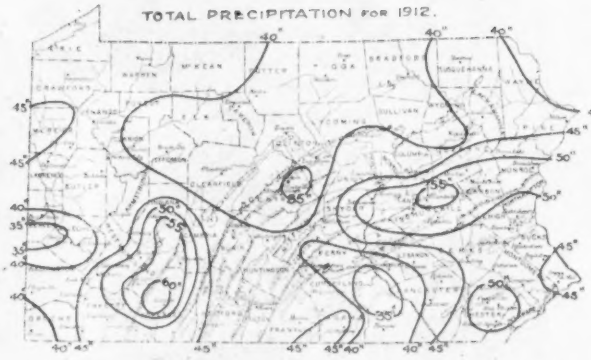

TOTAL PRECIPITATION FOR 1911.

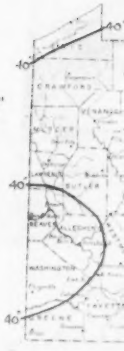
ECIPITATIONS IN PENNSYLVANIA

ITATION FOR 1909.

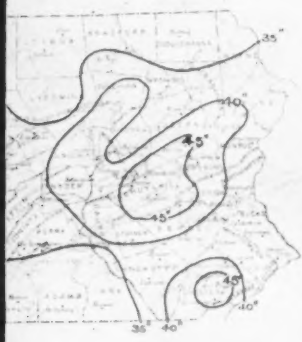


TOTAL PRECIPITATION FOR 1912.

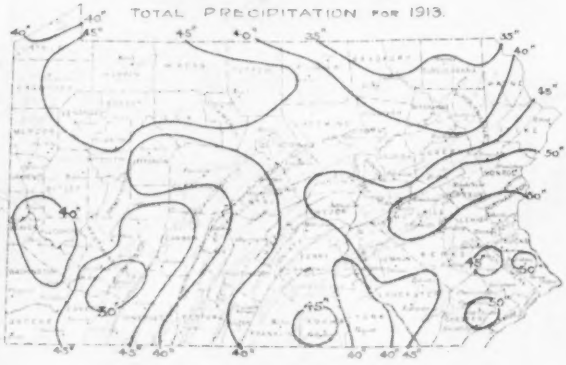




PITATION FOR 1910.

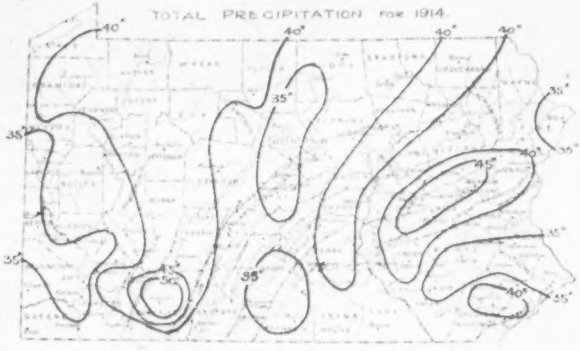


TOTAL PRECIPITATION FOR 1913.

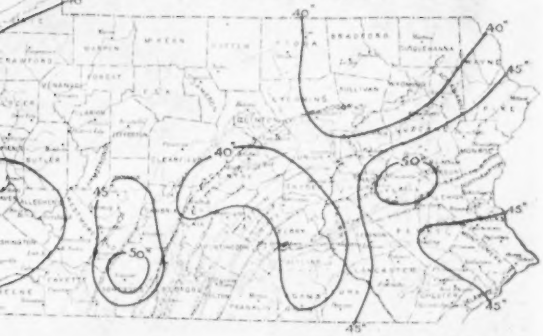


PITATION FOR 1911.

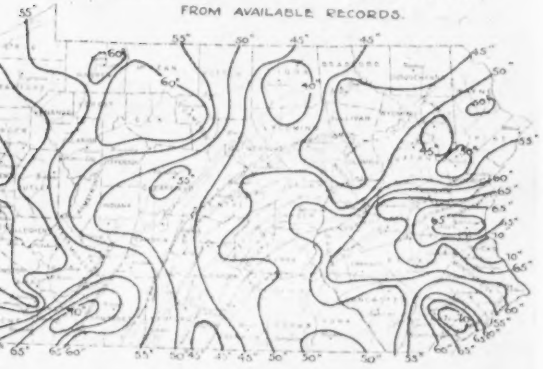
TOTAL PRECIPITATION FOR 1914.



MEAN ANNUAL PRECIPITATION. 1891-1913.



OCCURENCE OF MAXIMUM PRECIPITATION.
FROM AVAILABLE RECORDS.



OCCURENCE OF MINIMUM PRECIPITATION.
FROM AVAILABLE RECORDS.

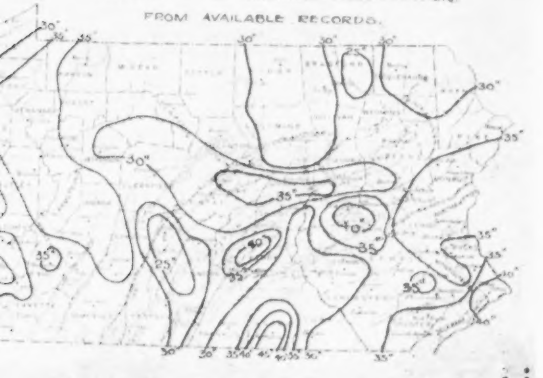


TABLE 2

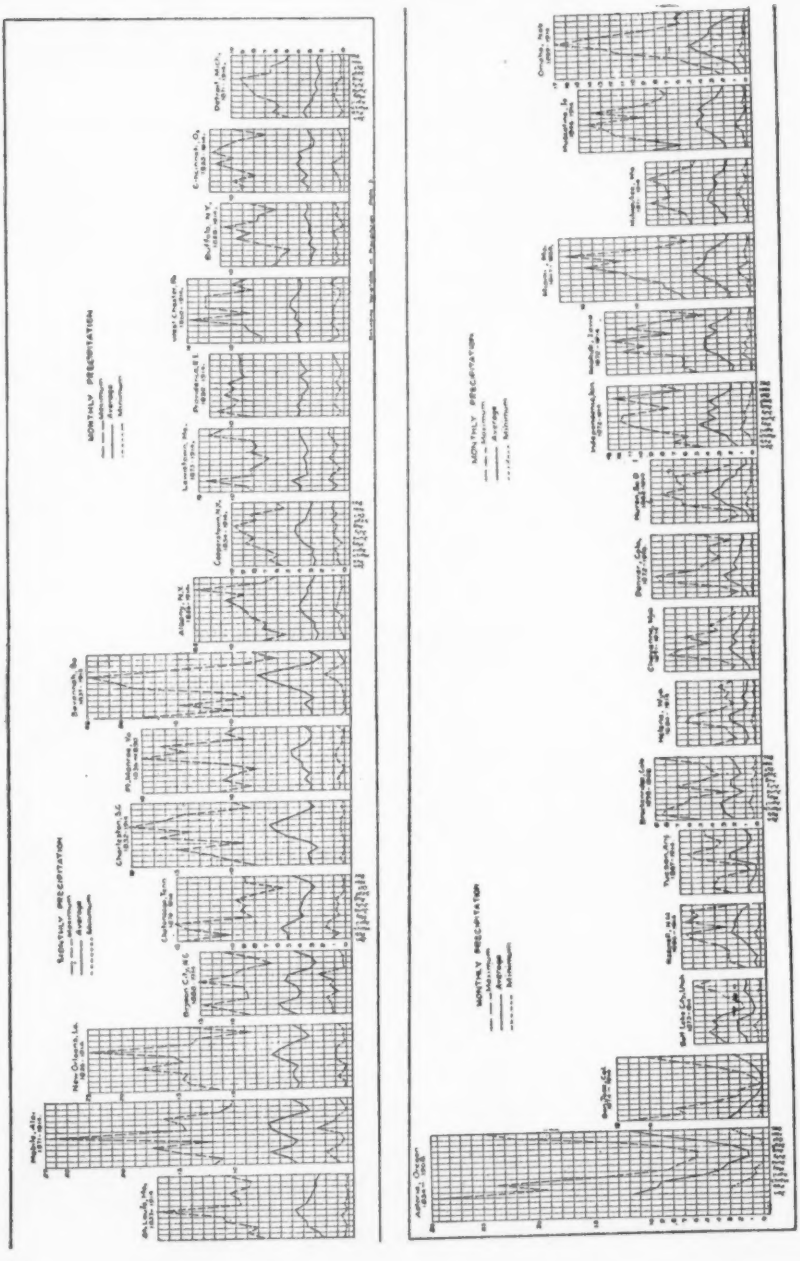
Monthly and annual averages of precipitation at Philadelphia, Pa., for different intervals

MONTHS	AVERAGE PRECIPITATION IN INCHES			
	Years 1895-1914	Years 1871-1914	Years 1860-1914	Years 1820-1914
January	3.13	3.26	3.34	3.25
February	3.33	3.31	3.41	3.32
March	3.71	3.54	3.65	3.41
April	3.37	3.05 min.	3.23	3.04
May	3.22	3.26	3.75	3.26
June	3.52	3.32	3.60	3.31
July	4.13	4.19	3.97	4.13
August	5.05 max.	4.77 max.	4.65 max.	4.73 max.
September	3.30	3.38	3.64	3.36
October	3.22	3.09	3.21 min.	3.03 min.
November	3.02 min.	3.15	3.29	3.13
December	3.69	3.21	3.28	3.13
Annual	42.70	42.07	43.02	41.66

MONTHLY PRECIPITATION

The month is convenient as a subdivision of climatic seasons or hydrologic periods, as well as for a unit in studying the relation between rainfall and runoff, but it is obviously too short an interval to estimate reliably for appreciable quantities, save where a distinct rainy season exists. Variations in total amounts deposited during the different months are graphically shown on plate 5; and plate 6 illustrates these divergences for one location. It is important in hydraulic studies to learn as far as possible the extremes which may occur in separate months, and the character of the occurrence of the precipitation, for these affect the capacity of storage and the provisions for excess water.

Overlappings of runoff ratios into the succeeding month are obviously more usual in large drainage areas, and in the smaller basins they can be discarded as exceptions or compensated. In addition to these, and the individual character of the watershed, the manner of occurrence is important, for this causes the disproportionate runoffs from falling and melting snow, and between moderate rains during the humid seasons and heavy downpours in short intervals during hot months. It is important to recognize the true value of


MONTHLY PRECIPITATION
Maximum
Average
Minimum
PRECIPITATION

a monthly average, for quantities which can not be utilized because of their surplus are to be discarded, and a true usable average determined.

Abnormal monthly precipitation totals have, in many instances, represented a large proportion of the annual accumulation, and while a succession of two separate monthly maxima or minima has been instanced, in general the distributions of these extremes are well scattered.

Some chronicles have shown the years of greatest and least precipitation to contain no extreme record for any specific month, and a few examples are given.

TABLE 3

Occurrence of extreme monthly amounts in years of maximum and minimum precipitation

LOCATION	INTERVAL	MAXIMUM YEAR INCLUDED MAXIMUM MONTHLY RECORD OF	MINIMUM YEAR INCLUDED MINIMUM MONTHLY RECORD OF
Block Island, R. I.	1881–1914		
Boston, Mass.	1818–1914	July	
Chicago, Ill.	1871–1914	May and October	
Davenport, Iowa	1872–1914		August
Denver, Colo.	1872–1914	February and September	
Dubuque, Iowa	1851–1914	February	February and October
Indianapolis, Ind.	1872–1914		September
Nashville, Tenn.	1871–1914	February and October	
New Orleans, La.	1836–1914	February	
New York, N. Y.	1871–1914	July and November	
Oklahoma, Okla.	1891–1914	February, April and October*	July
Pittsburgh, Pa.	1872–1914	December	
Raleigh, N. C.	1887–1914		June
Richmond, Va.	1872–1914	April, May, June and July	January
Rochester, N. Y.	1871–1914	March and October	
St. Louis, Mo.	1837–1914	August	August
Salt Lake City, Utah.	1875–1914	November	

* This year also included the minimum December record.

The charts of Mr. B. C. Wallis showing equipluves for each month and the regions in which specific months show the greatest and least water received indicate a variation in these that is dissimilar to records for the year and for precipitation in brief intervals.

The accompanying Table 4 indicates one instance of distribution, in which the year of maximum annual precipitation included no maximum month, and only one minimum monthly record occurred in the year of least precipitation. Two years experienced 2 of the maximum monthly records, one of these also including a minimum monthly, 2 years included a minimum monthly, of which 1 year also had a maximum for a month, and 4 other years gave both a maximum and minimum monthly record. In total the maximum and minimum monthly records were each distributed among 10 years, and 74 per cent of the years experienced one extreme of monthly total.

TABLE 4

Extremes of monthly precipitation at Williamsport, Pa, 1896-1914

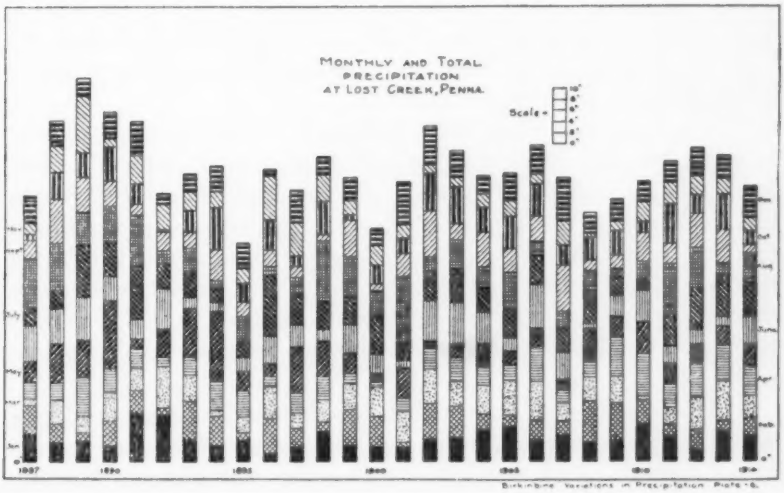
MONTH	MAXIMUM		MONTH	MINIMUM	
	Inches	Year		Inches	Year
January	4.25	1913	January	1.21	1912
February	5.08	1908	February	0.66	1901
March	5.11	1904	March	0.42	1910
April	8.22	1909	April	0.81	1900
May	6.34	1901	May	1.28	1911
June	7.16	1907	June	0.79	1912
July	8.01	1908	July	0.75	1909
August	9.65	1912	August	0.94	1907
September	5.65	1902	September	0.81	1898
October	5.92	1898	October	0.92	1910
November	3.46	1897	November	0.51	1904
December	6.05	1901	December	0.89	1896
Annual	43.64	1905	Annual	29.94	1900

EXTENSIVE PRECIPITATION

Not only for the much greater demands of industries are large streams and rivers drawn upon for water supply, but with the development of purification methods these furnish large quantities for general and domestic purposes. Where the usage is purely industrial an equal warrant for uninterrupted supply is less necessary

than when the health and safety of a community are considered, but the financial investment demands protection against excessive damage or destruction. On most large streams the demands for lower riparian rights, sanitation, and in some instances navigation, so restrict the allowable draft that minimum flow conditions do not limit the supply. Flood conditions may damage structures or equipment, and affect existing mains.

In general, severe floods from large drainage basins are due to excessive rainfall. Aside from the quantity of rain and character of basin the effect is modified by dry, hard, moist, saturated or frozen



ground, and frozen or melting snow. But a large number of severe floods have been caused by rainfall only, occurring at a season when absorption by air and vegetation is high. The most severe flood on the Schuylkill River in Pennsylvania occurred in early September, 1850, and on October 4 and 5, 1869, was registered the second highest flood conditions on the upper river and the maximum heights on the lower reaches.

The Passaic River in New Jersey, in October, 1903, reached extreme flood stages, and the rainfall records are notable for the severity. Mr. C. C. Vermeule computed the average rainfall on the watershed, based on 11 stations, to be:

October 8	2.21 inches
October 9	7.83 inches
October 10	1.55 inch
October 11	0.39 inch
	11.98 inches

Individual stations reported quantities from $9\frac{3}{4}$ inches to $15\frac{1}{2}$ inches for the 4 days, and among the rainfalls were:

Newark, $68\frac{1}{2}$ hours	11.83 inches
Ringwood, 33 hours	10.63 inches
Essex Falls, 48 hours	10.66 inches

while 24 hour amounts reached 11.45 inches at Paterson, and above 8 inches at 3 other stations on the watershed, and many others received from 6 inches to 8 inches.

This rainfall was remarkable, not only for its continuance and severity, but also because of its intensity for some intervals, New York City recording 2.42 inches in 2 hours, and Newark 1.20 inches in 1 hour; and of the large area affected. The average precipitation for New Jersey, for this month, and nearly all of which fell during this storm, was nearly $2\frac{1}{2}$ times the normal. Adjacent areas were affected, and not only did small streams overflow, but the Delaware River at Phillipsburg and Lambertville reached its maximum crests.

Another feature of note is that this followed a summer of precipitation above normal, which was reflected in the water content of the ground. As a result, the 1903 storm, according to Mr. Vermeule, produced a runoff on the Passaic basin of nearly 60 per cent, more than twice the proportion from the rains of September 1882; for, although the earlier occasion gave a greater total precipitation, it followed a summer of deficient rain.

The floods on the Saginaw and Grand Rivers, Michigan, in May 1912; on the Wisconsin River at Wausan in July 1912; and the Cherry Creek flood at Denver, July 14 1912, are respective examples of continued rains covering a number of days, of severe rain within a calendar day, and of an intense storm in a short interval.

The most pronounced instance of excessive rain over an extended area is the Ohio Valley disaster of 1913. While the runoff was intensified by the moist condition of the soil, there were fortunately no material quantities of snow on the higher areas, and the unusual

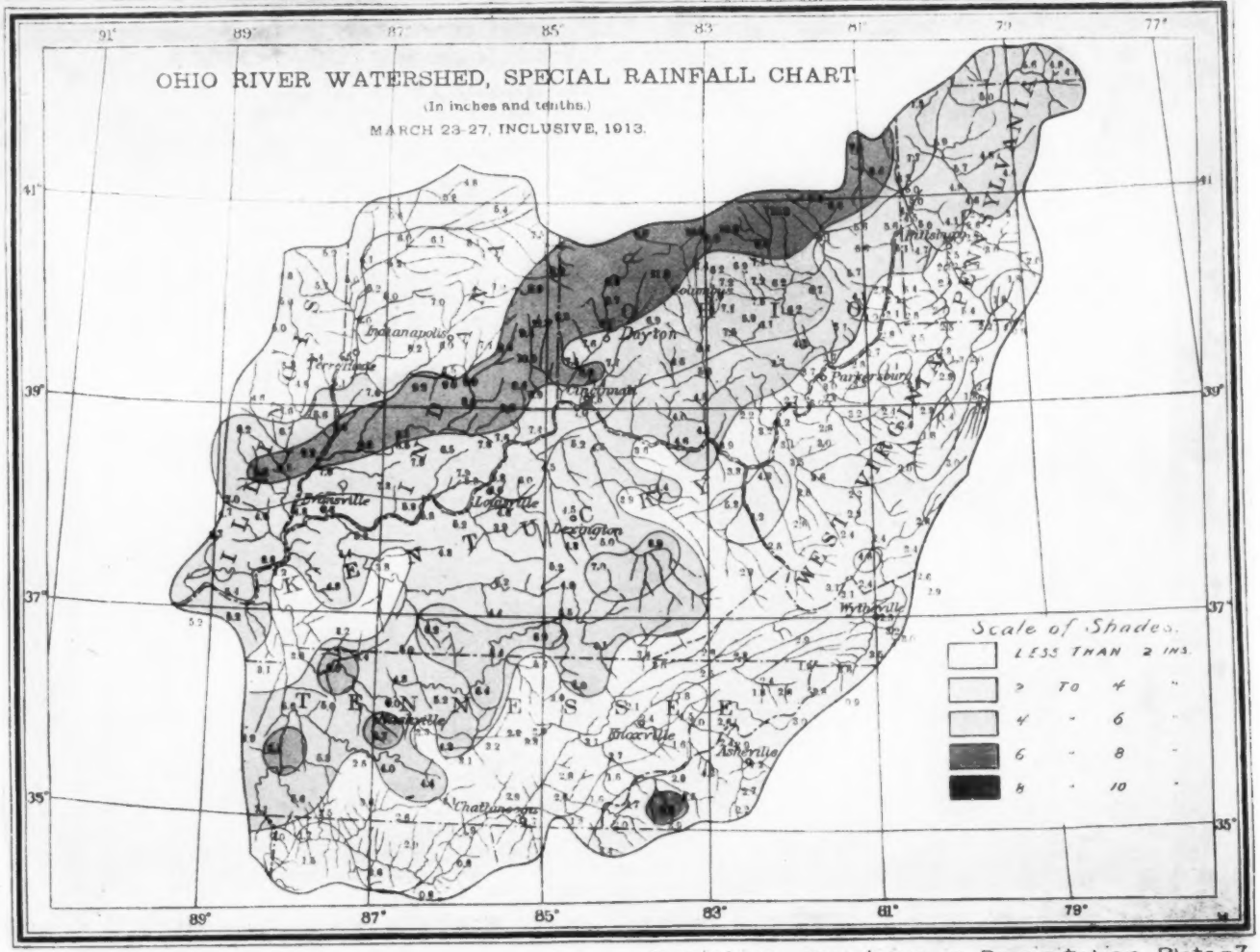
rainfalls due to different storms in close succession are shown on plate 7, while 6.66 inches in 1 day, Shoals, Indiana, March 25, and 9.20 inches in 3 days, Bellefontaine, Ohio, illustrate the intensity of rainfall at times. Heavier 24-hour and 72-hour totals have been recorded for the affected region, but the total area covered by extreme rains has not been equalled since records have been kept.

Prof. J. Warren Smith has calculated that the 5-day rainfall on 9 watersheds, draining from 1025 to 7693 square miles, ranged from 6.94 inches, on the largest of these basins, to 8.68 inches, on an area of 1567 square miles, giving total depositions of from 15,000,000 to 20,000,000 cubic feet per square mile. Prof. A. J. Henry estimated the total excess discharge at Parkersburg, West Virginia, due to an average rainfall on the watershed of 4.7 inches as nearly 300,000 million cubic feet.

The latter part of March 1913, also witnessed abnormal rainfalls which established new flood records on the Genesee River at Rochester, on the Hudson River at Mechanicville and Albany and on many tributaries; and severe floods occurred on the Connecticut River, producing the maximum recorded stage at Brattleboro, Vermont. The conditions extended to other states, it being the wettest March in Ohio, Indiana, New York, Pennsylvania, South Carolina, Georgia and Alabama, and unusual quantities fell at adjoining localities.

The flood of 1889, which devastated Johnstown, Pennsylvania, and established record flood heights on the Susquehanna River, was caused by the unusual quantities of precipitation. Mainly the heaviest rains occurred on May 31, though 40 stations received rain on June 1, while 22 of these showed more than 1 inch, and 4 had more than 3 inches on that day. This storm was marked by some severe downpours, Grampian Hills having 6 inches in 7 hours and Harrisburg 8 inches in 18 hours. No rain was noted on June 2, but this month was characterized by frequent and heavy rainfalls, the average for Pennsylvania stations being 15 days with rain and 5.43 inches total.

Frequent rains, each of moderate amount, have produced damaging floods by so saturating the soil and filling water courses that the later rains became a direct runoff. Flood channel and spillway design are contingent on such conditions, the latter requiring not only ample width and depth, stability, and shape of crest, but also proper design of rollway, that the passage of water over the face will



Birkinbine Variations in Precipitation. Plate.-7.

follow proper lines, but the apron must be so laid out that water discharging from it will not undercut the structure or erode the river bottom, and thus set up damaging currents. Flood conditions, especially when occurring at the close of winter, frequently produce in reservoirs an upper stratum of water that demands purification because the continuous excess inflow carries the washings from the watershed.

DAILY PRECIPITATION

The precipitations in brief intervals are important because of the large quantities sometimes deposited. The actual duration of the reception of moisture is generally much less than 24 hours, which is merely a unit of interval. In fact the actual total period of precipitation is for many localities but a small portion of the day.

Plate 10 illustrates some instances of the proportion which unusual excessive daily amounts bear to the monthly and annual totals, and they have been grouped so as to show the relative importance of these daily measures.

The effect of daily quantities upon turbidity is illustrated on plate 9, compiled by courtesy of the Water Department of Reading, Pennsylvania. The low and constant turbidity in the early and late months of the year was due to the precipitation during these intervals being mainly frozen; and small variations in turbidity in portions of November and December are explained by low temperature and moderate rate of precipitation. The high turbidities following the rains of June 2 (0.75 inch) and August 10 (1.08 inch), and the lower degree subsequent to the rains of June 6 (1.60 inch), July 11 (2.68 inches and preceded by 1.15 inch on the previous day), September 24 (2.26 inches), and October 23 (1.92 inch), can be explained by differences in intensity of precipitation.

Continuous precipitations for more than a day give small totals except when caused by a succession of storms. They are infrequent, save where a marked rainy season occurs.

CONTINUOUS PRECIPITATION

Precipitations of continued duration must be defined by their intensity and by local rainfall characteristics. Galveston affords some examples of what may be termed almost tropical rainfalls, one of which is illustrated on plate 14, and the Gulf region is subjected to

PLATE 10

Some twenty-four hour precipitations and their relation to total monthly and annual amounts. All quantities in inches

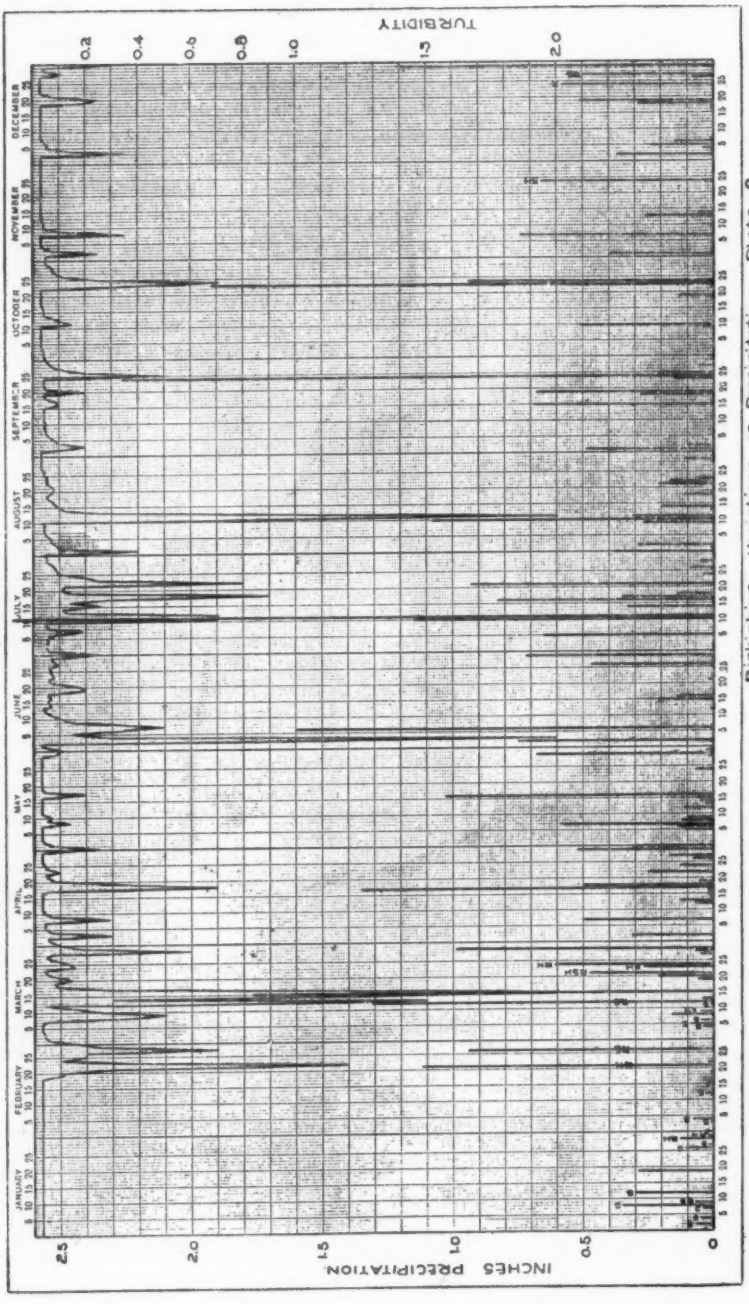
LOCATION	DATE	TOTAL PRECIPITATION IN		
		Twenty-four hours	Month	Year
Atlantic City, N. J.	October, 1903	9.21	12.13*	61.11
Columbia, Mo.	September, 1905	6.13	11.54*	47.03
Evansville, Ind.	October, 1910	6.94	11.19*	45.46
Galveston, Tex.	July, 1900	14.35	18.74*	69.66
Galveston, Tex.	October, 1901	14.10	15.00*	51.33
Jacksonville, Fla.	May, 1903	9.06	14.80*	52.03
Knoxville, Tenn.	September, 1898	5.68	7.44*	42.79
Little Rock, Ark.	April, 1913	9.58	11.46*	61.57
La Crosse, Wis.	October, 1900	7.23	12.09*	41.85
Lynchburg, Va.	October, 1902	7.18	9.86*	48.79
Montgomery, Ala.	January, 1892	9.98	17.78*	69.85
New York, N. Y.	October, 1903	9.40	11.55*	48.60
New Orleans, La.	March, 1903	8.66	14.61*	57.18
Pensacola, Fla.	September, 1906	7.68	16.48*	47.05
Savannah, Ga.	August, 1910	8.56	11.75*	46.61
Topeka, Kan.	September, 1909	8.08	11.48	46.96
Vicksburg, Miss.	March, 1902	7.12	12.96*	47.31
Washington, D. C.	September, 1904	5.00	5.34*	40.84
Cambridge, Ohio	July, 1914	7.09	8.36*	44.42
Concordia, Kan.	July, 1907	5.69	5.91*	24.05
Corpus Christi, Tex.	February, 1893	5.80	6.27*	20.50
Davenport, Ia.	June, 1905	5.06	7.68*	31.54
Fort Smith, Ark.	April, 1893	4.98	7.89*	44.70
Galveston, Tex.	April, 1904	9.23	11.04*	42.65
Indianapolis, Ind.	September, 1895	6.80	7.46*	33.54
Kansas City, Mo.	July, 1896	5.62	8.66*	33.64
Kearney, Neb.	May, 1893	3.72	7.49*	22.86
Lincoln, Neb.	August, 1910	8.38	14.21*	31.33
Madison, Wis.	August, 1906	5.07	7.56*	32.38
Moorhead, Miss.	June, 1894	4.08	7.70*	22.43
Omaha, Neb.	August, 1903	7.03	12.50*	33.43
Shreveport, La.	December, 1904	7.18	9.62*	35.29
St. Paul, Minn.	July, 1892	5.67	9.04	32.55
San Luis Obispo, Cal.	January, 1901	5.04	11.21*	25.76
Topeka, Kan.	October, 1912	5.70	7.05*	31.92
Yankton, S. D.	July, 1900	7.52	13.27*	31.38

* Indicates highest monthly total in the year.

PLATE 10—Continued

LOCATION	DATE	TOTAL PRECIPITATION IN		
		Twenty-four hours	Month	Year
Amarillo, Tex.	July, 1910	2.17	3.57*	11.15
Bismarck, N. D.	September, 1894	3.67	3.83*	14.32
Boise, Id.	March, 1904	2.46	5.39*	14.08
Cheyenne, Wyo.	July, 1896	4.70	6.35*	20.79
Dodge City, Kan.	July, 1893	2.05	3.32*	10.12
Los Angeles, Cal.	May, 1898	1.46	1.75*	4.83
Los Angeles, Cal.	November, 1900	3.79	6.53*	11.30
Modena, Utah	July, 1907	2.17	2.46*	12.80
North Platte, Neb.	June, 1894	1.94	3.54*	11.21
Oklahoma, Okl.	April, 1910	3.75	4.31*	17.27
Pierre, S. D.	June, 1895	3.32	6.09*	16.85
Pueblo, Colo.	May, 1894	2.48	3.76*	12.64
Rapid City, S. D.	May, 1899	4.24	6.76*	16.71
Salt Lake City, Utah	May, 1901	2.72	4.27*	16.08
Santa Fe, N. M.	September, 1904	2.51	5.37*	14.19
St. Paul, Minn.	May, 1910	1.37	1.76*	10.21
Sioux City, Ia.	April, 1913	3.08	5.50*	20.31
Walla Walla, Wash.	May, 1906	2.74	4.81*	19.13
Brawley, Cal.	August, 1909	1.22	1.43*	3.69
Carson City, Nev.	March, 1903	1.34	1.56	6.23
Del Rio, Tex.	April, 1910	2.52	3.30*	9.06
Denver, Colo.	May, 1893	1.41	3.09*	8.48
El Paso, Tex.	June, 1910	1.02	1.35*	4.03
Havre, Mont.	June, 1895	1.70	3.36*	10.94
Independence, Cal.	February, 1902	1.41	1.69*	3.83
Independence, Cal.	September, 1910	0.72	0.72*	2.37
Miles City, Mont.	August, 1900	3.36	4.58*	10.55
Phoenix, Arix.	February, 1901	0.80	1.46	4.87
Phoenix, Ariz.	September, 1903	1.72	3.16*	6.61
Reno, Nev.	July, 1910	1.20	1.45*	5.97
Reno, Nev.	August, 1912	0.96	0.96*	4.66
Roswell, N. M.	August, 1910	1.01	2.03*	4.87
Tonopah, Nev.	May, 1913	0.86	1.11	6.75
Yuma, Ariz.	March, 1893	0.54	1.29*	3.00
Yuma, Ariz.	November, 1899	0.50	0.50*	0.60
Yuma, Ariz.	August, 1909	4.01	6.25*	8.63

* Indicates highest monthly total in the year.



Birkinbine. Variations in Precipitation. Plate-9

continuous rainfalls which are unknown to many other localities; Austin, Texas, being said to have had a 64-hour rainfall in July, 1869. The Pacific Coast, with its distinct winter season, is also subject to rains of extended duration.

It is not important whether an extended rainfall is entirely continuous or is broken by small intervals of no deposition, for any excess of water on saturated ground will produce high runoffs. But the distinction between the combined rainfall of several severe storms and continuous moderate rains is illustrated by the accompanying Table 5 of some rains in Baltimore, Maryland, which has experienced several severe storms of brief duration and great intensity.

TABLE 5

Some continuous precipitations at Baltimore, Md.

DATE	HOURS DURATION	TOTAL PRECIPITATION IN INCHES	AVERAGE RATE PER HOUR IN INCHES
April 19–21, 1893	44	1.14	0.026
April 10–12, 1894	52	1.95	0.036
December 10–12, 1894	49	2.01	0.041
January 8–10, 1895	55	1.55	0 028
April 27-May 1, 1895	102	3.69*	0 036
November 24–25, 1895	42	0.13	0.003
December 3–5, 1897	44	1.18	0 027
February 18–21, 1898	47	1.18	0.025
December 3–4, 1898	44	1.27	0 03
February 11–13, 1899	54	1.56	0 029
February 16–17, 1900	41	0.40	0.01
February 20–22, 1902	51	2.53	0 05
November 24–26, 1902	44	1.60	0 036
April 13–15, 1903	43	1.68	0 039

* At times the rate was excessive.

Professor Fassig listed 14 rain and snow storms of long duration at Baltimore for the period from April 1893, to April 1903, of which he says: "In these storms the rainfall was practically continuous, although in most of them there were intervals of a few hours during which only light sprinkling or misting rains were recorded."

INTENSE STORMS

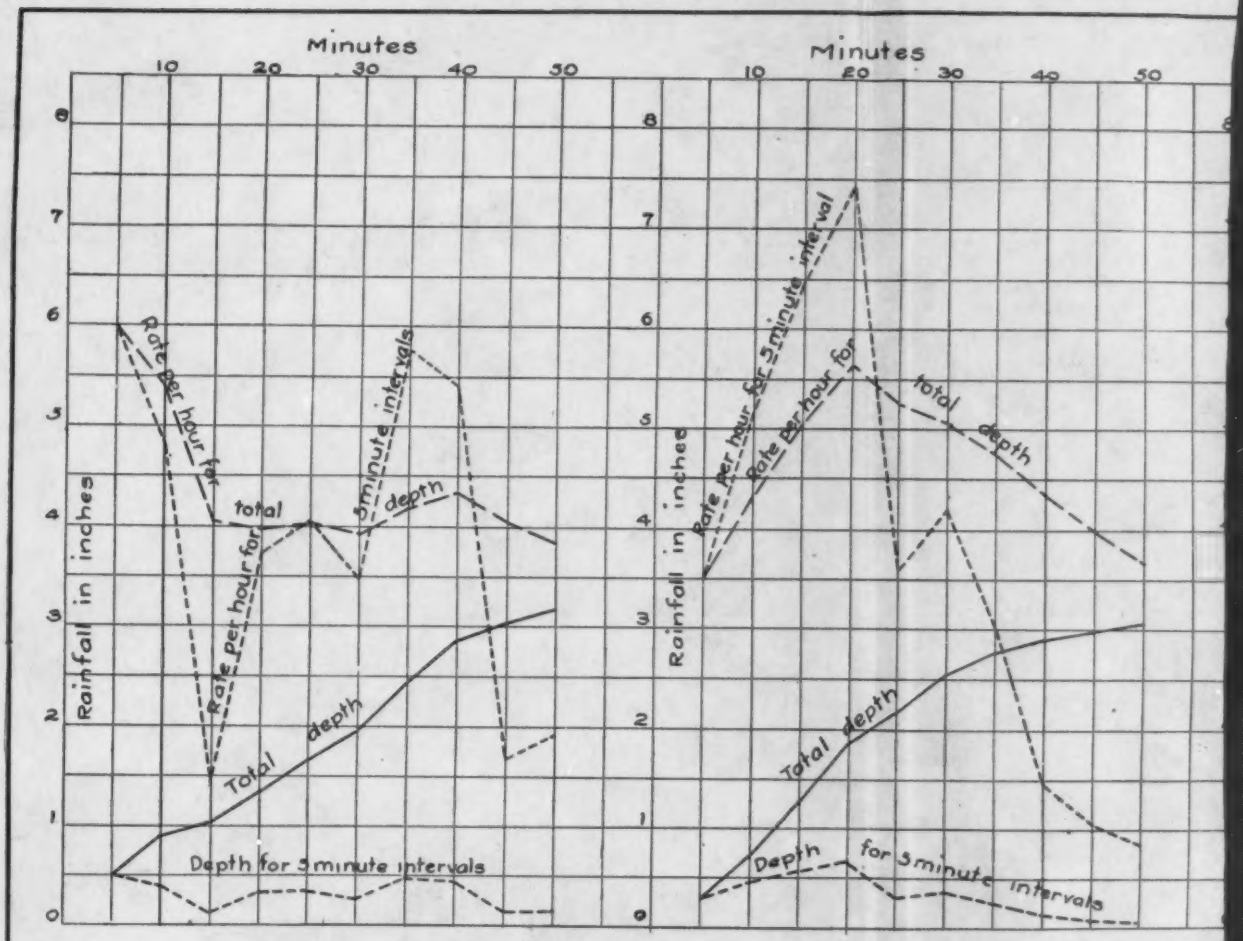
It is fortunate that the intensity of rainfall decreases with its duration, but the severity of local storms cause much damage. Many maximum 24-hour precipitations actually occur, most or all, in a few hours, and their geographic distribution differs widely from that of total annual precipitation.

The relative value of amounts deposited is important, for an extraordinary rain in some regions would not be considered unusual in other localities. On February 26, 1914, at Los Angeles, California, a precipitation of 2 inches in 2 hours overtaxed the street drainage system; the destructive flood of January 14, 1903, at Heppner, Oregon, which cost 200 lives, was due to an estimated fall of 1½ inch in 30 minutes over 21 square miles; and 0.76 inch in one hour at Pocatello, Idaho, on June 8, 1912, was but 0.01 inch below the record for such an interval.

Intense storms over small drainage areas have given the maximum runoff records, and it is unfortunate from the standpoint of information that in so many cases either or both rainfall and runoff records are not available. It is to be noted that such rains usually occur at a season when high temperatures of earth and air, and the growing state of vegetation, exert their influences in absorbing moisture. Such storms are of slight value in repletion of subsurface waters, the water being mainly carried away by direct runoff, hence but a small portion of it benefits underground reserves.

Plates 11 to 14 illustrate the quantities and rates of rainfall for the total period and for 5 minute intervals, as far as they are available, for various storms at different localities, as measured by recording gauges. These illustrate graphically, in different instances, the varying rates of intensity, the occurrence of more than one peak in the rate, the growing or decreasing severity as the storm continues, and the high rates reached at intervals. Some of such variations of high rates after the storm has been in progress are especially unfavorable, for 2 inches in 30 minutes is more severe when half of it falls in the last third of the period.

Such storms may entirely cover a small drainage area, and the duration of the downpour, the limited extent of the watershed or its configuration, may, singly or in combination, produce concentrated runoffs that fall into a special class because of their magnitude, and require estimation similar to storm water flow for cities.

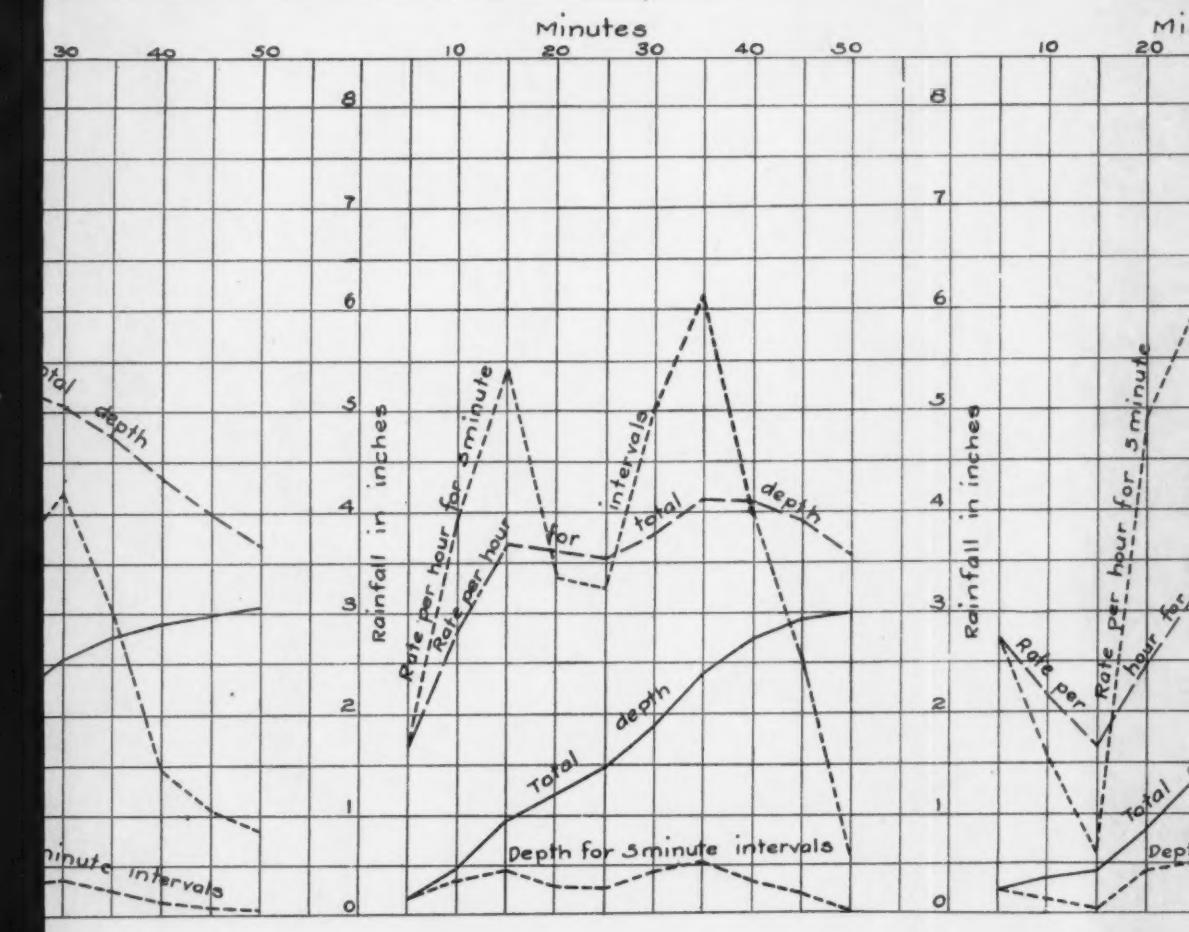


Rainfall at Atlanta, Ga Aug. 20, 1914.
9.54 A.M to 10.45 A.M.

Maximum Precipitation
In 5 minutes = 0.50
In 10 minutes = 0.93.
In 15 minutes = 1.22

Rainfall at Lincoln, Nebraska. July 25, 1914.
5.29 P.M to 6.19 P.M.

Maximum Precipitation
In 5 minutes = 0.62
In 10 minutes = 1.16
In 15 minutes = 1.59



July 25, 1914.
6.18 P.M.
= 0.62
= 1.16
= 1.59

Maximum Precipitation

Rainfall at Bismarch, N.D. Aug. 9, 1909.
10.55 P.M. to 11.41 P.M.
In 5 minutes = 0.31
In 10 minutes = 0.93
In 15 minutes = 1.26

Maximum Precipitation

Rainfall at Wich
8.25 P
In 5 mi
In 10 mi
In 15 mi

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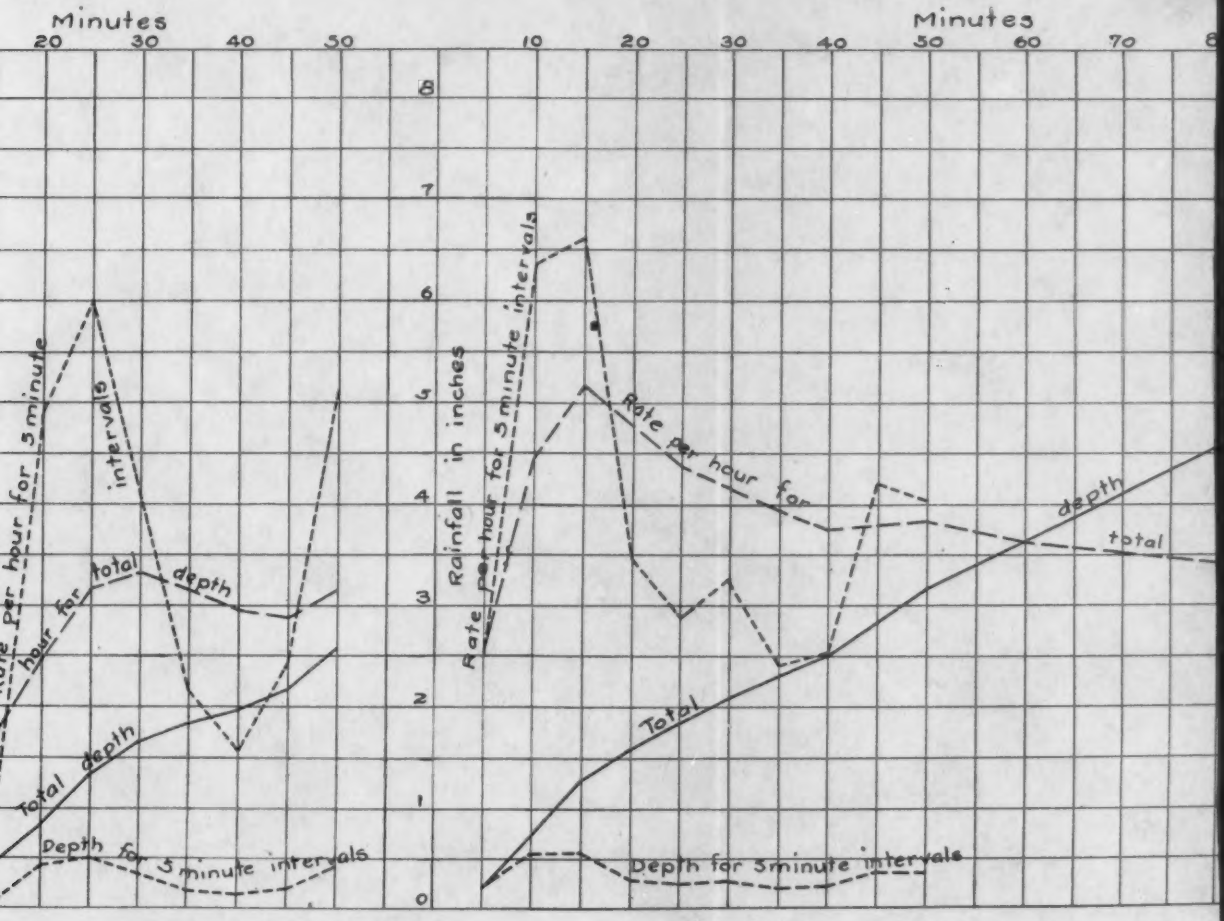
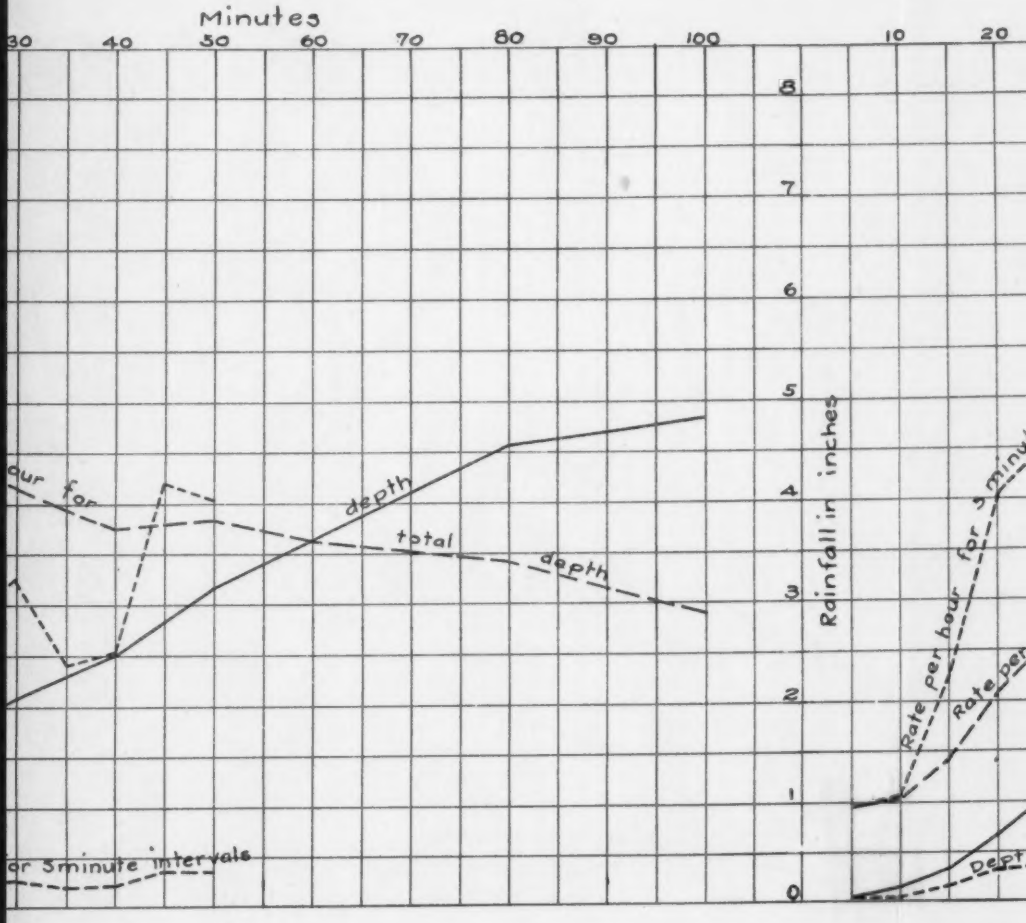


at Wichita Kansas, Sept. 17, 1905.
8.25 P.M. to 9.17. P.M.
In 5 minutes = 0.50
In 10 minutes = 0.91
In 15 minutes = 1.25

Maximum Precipitation

Rainfall at Madison Wisconsin, August
3.24 P.M. to 6.56 P.M.
In 5 minutes = 0.55
In 10 minutes = 1.08
In 15 minutes = 1.37



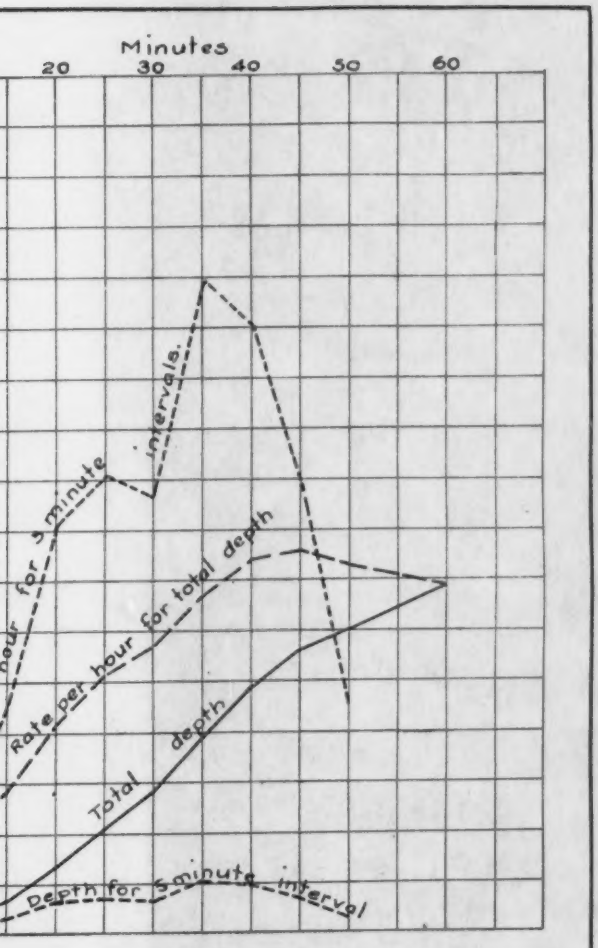
fall at Madison Wisconsin, August 8, 1906.

3.24 P.M. to 6.56 P.M.

In 5 minutes = 0.55
In 10 minutes = 1.08
In 15 minutes = 1.37

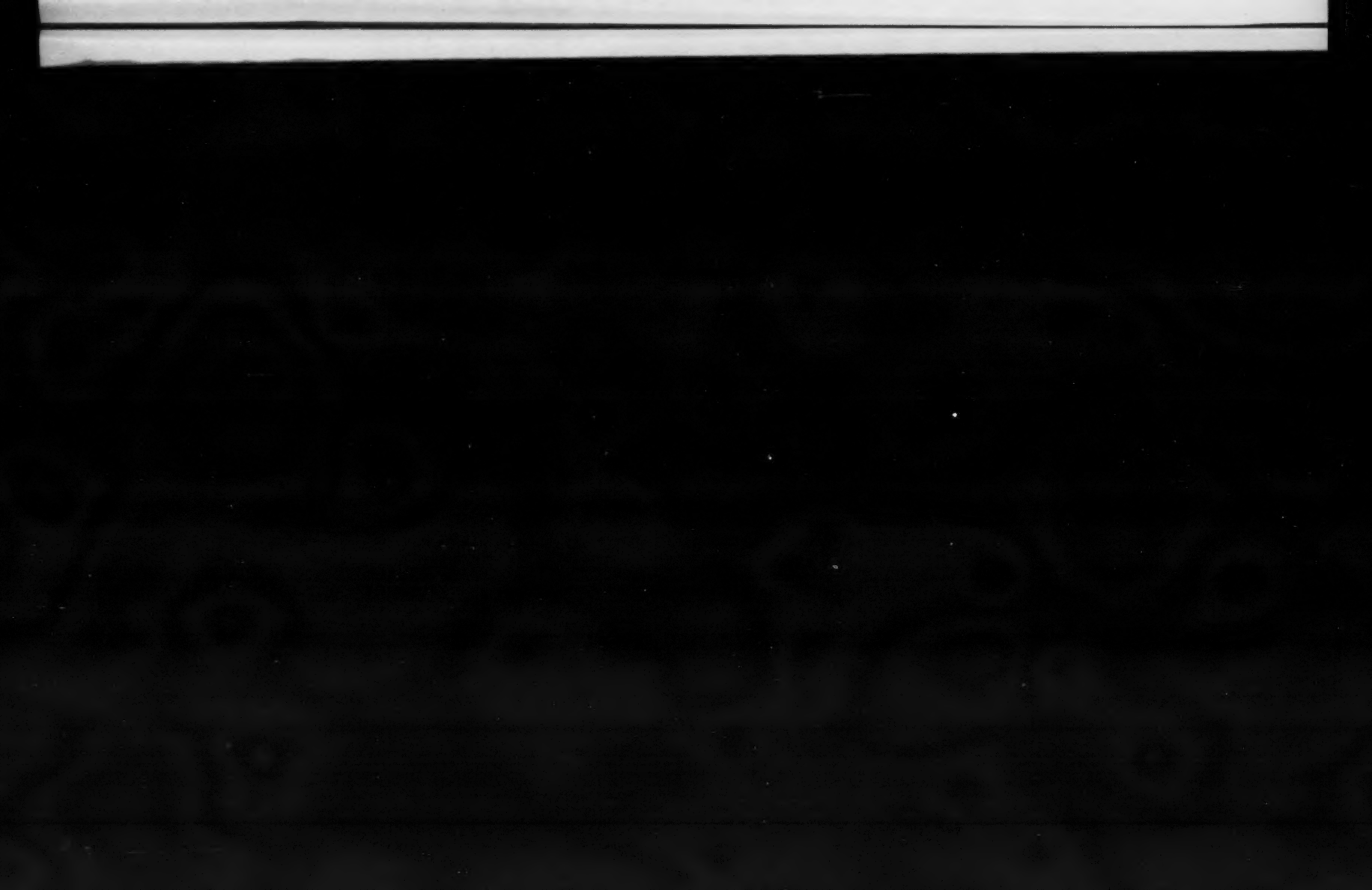
Maximum Precipitation

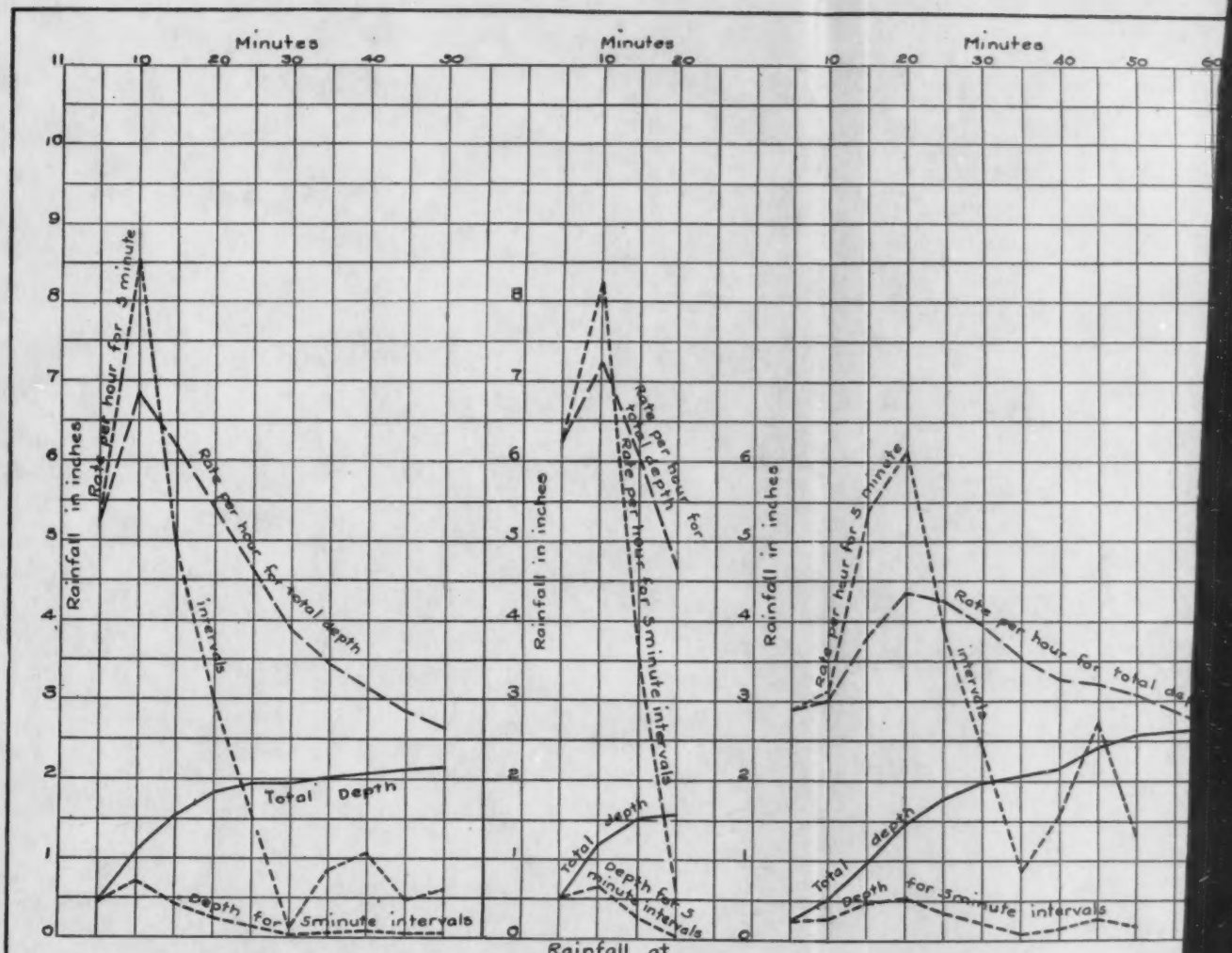
Rainfall a
10
In 5 m
In 10m
In 15m



nfall at Montgomery Ala. May 30,1905.
10.38 A.M to 11.39 A.M.
In 5 minutes = 0.34
In 10 minutes = 1.04
In 15 minutes = 1.41

PLATE 11





Rainfall at Saginaw, Mich. July 27, 1913. 3.33 P.M. to 4.21 P.M

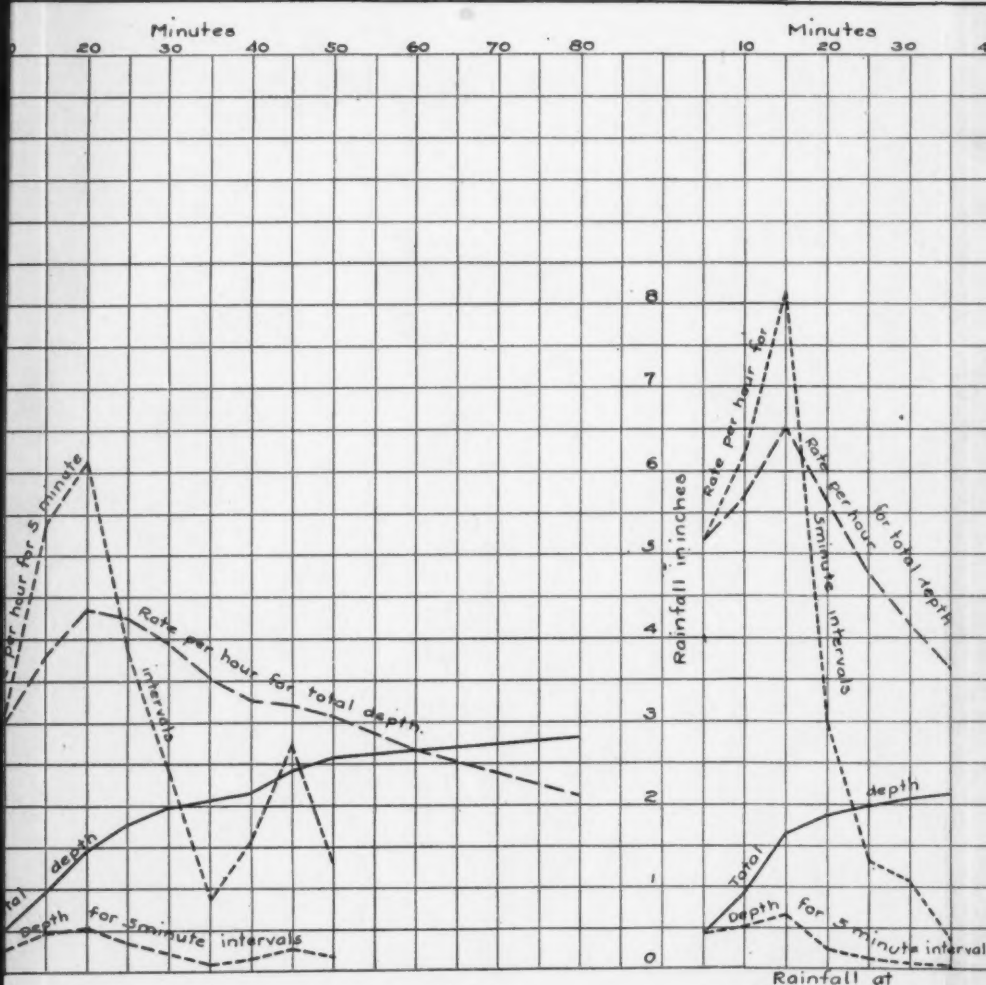
Maximum Precipitation
In 3 minutes = 0.71
In 5 minutes = 1.14
In 15 minutes = 1.55

Rainfall at Washington D.C. July 30, 1913. 3.10 to 3.27 P.M.

Maximum Precipitation
In 5 minutes = 0.69
In 10 minutes = 1.21

Rainfall at Indianapolis, Ind. 11.55 A.M. to 1.

Maximum Precipitation
In 3 minutes = 0.
In 10 minutes = 0.
In 15 minutes = 1.

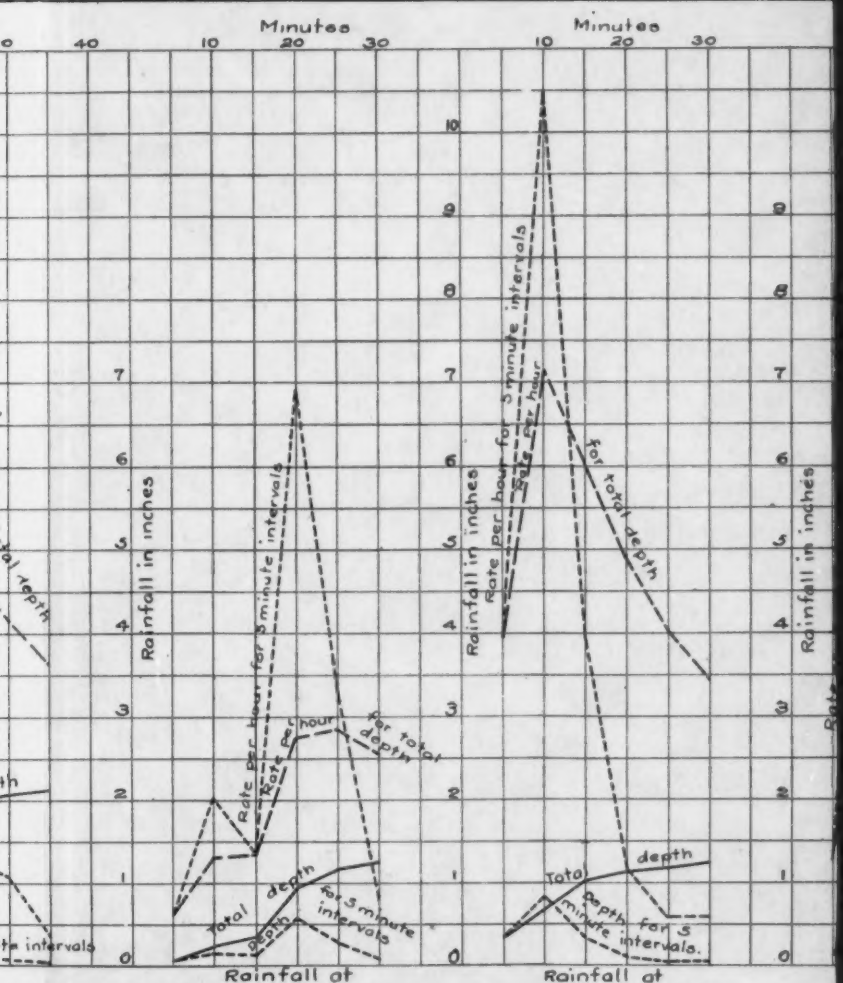


Rainfall at Indianapolis, Ind. August 13, 1913.
11.55 A.M. to 1.01 P.M.

Maximum Precipitation
In 5 minutes = 0.51
In 10 minutes = 0.96
In 15 minutes = 1.28

Rainfall at New York, N.Y. July 10, 190
3.32 P.M. to 4.04. P.M.

Maximum Precipitation
In 5 minutes = 0.68
In 10 minutes = 1.20
In 15 minutes = 1.63.


Minutes
Minutes
Rainfall in inches
Rainfall in inches
Rainfall in inches
Rate per hour for 5 minute intervals
Rate per hour for total depth
Total depth for 5 minute intervals
Rate per hour for 5 minute intervals
Rate per hour for total depth
Total depth for 5 minute intervals.

uly 10, 1905.
04. P.M.
= 0.68
= 1.20
= 1.63.
th
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Rainfall at Chicago, Ill. July 15, 1906.
11.17 A.M. to 11.47 A.M.
Maximum Precipitation
In 5 minutes = 0.64
In 10 minutes = 0.89

Rainfall at Denver Col. July 14, 1912.
3.34. P.M. to 4.05 P.M.
Maximum Precipitation
In 5 minutes = 0.87
In 10 minutes = 1.30
In 15 minutes = 1.62

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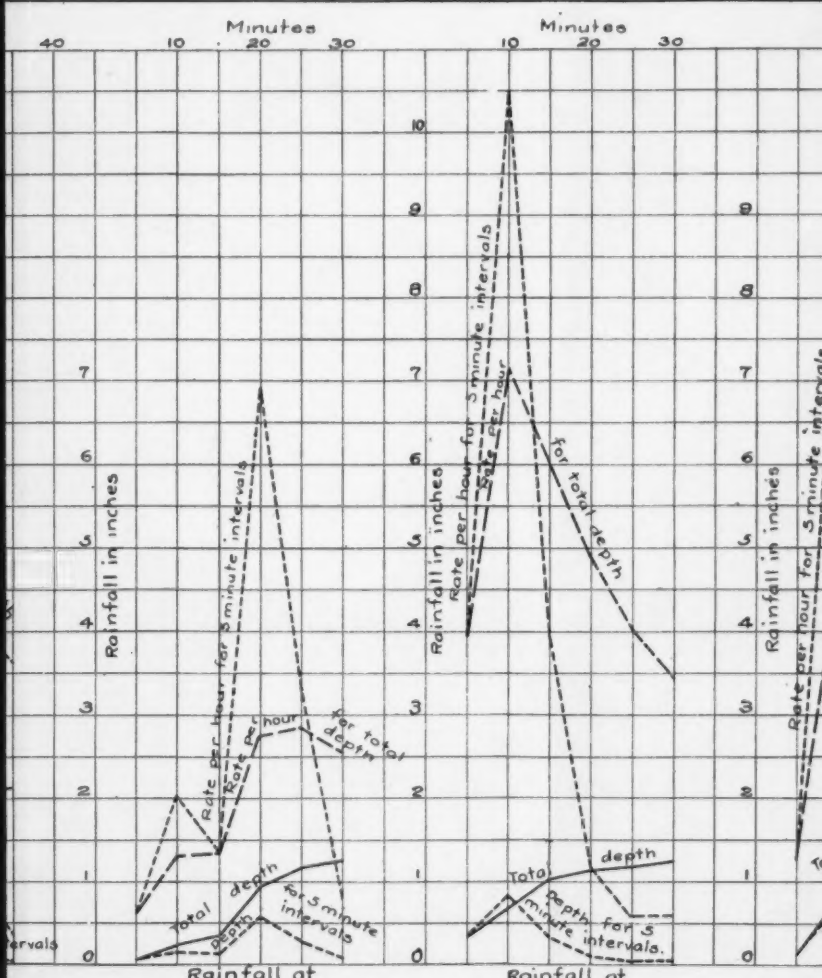

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Rainfall at Chicago, Ill. July 15, 1906.
11.17 A.M. to 11.47 A.M.
Maximum Precipitation
In 5 minutes = 0.64
In 10 minutes = 0.89

Rainfall at Denver Col. July 14, 1912
3.34 P.M. to 4.05 P.M.
Maximum Precipitation
In 5 minutes = 0.87
In 10 minutes = 1.30
In 15 minutes = 1.62

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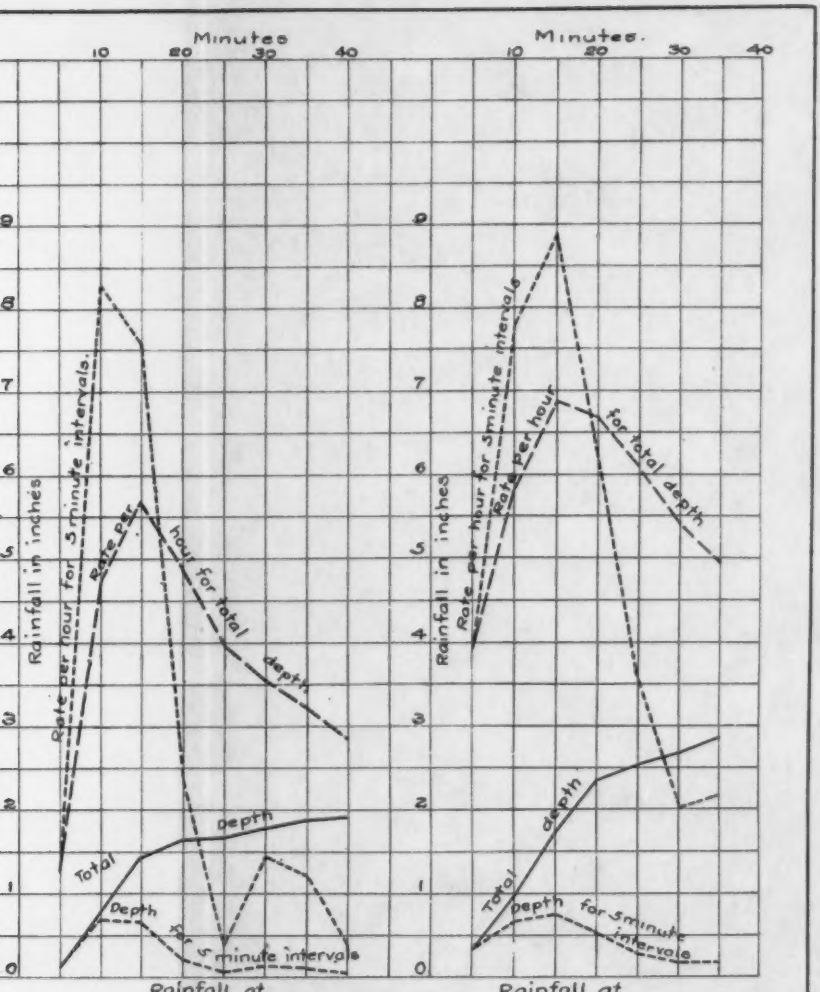


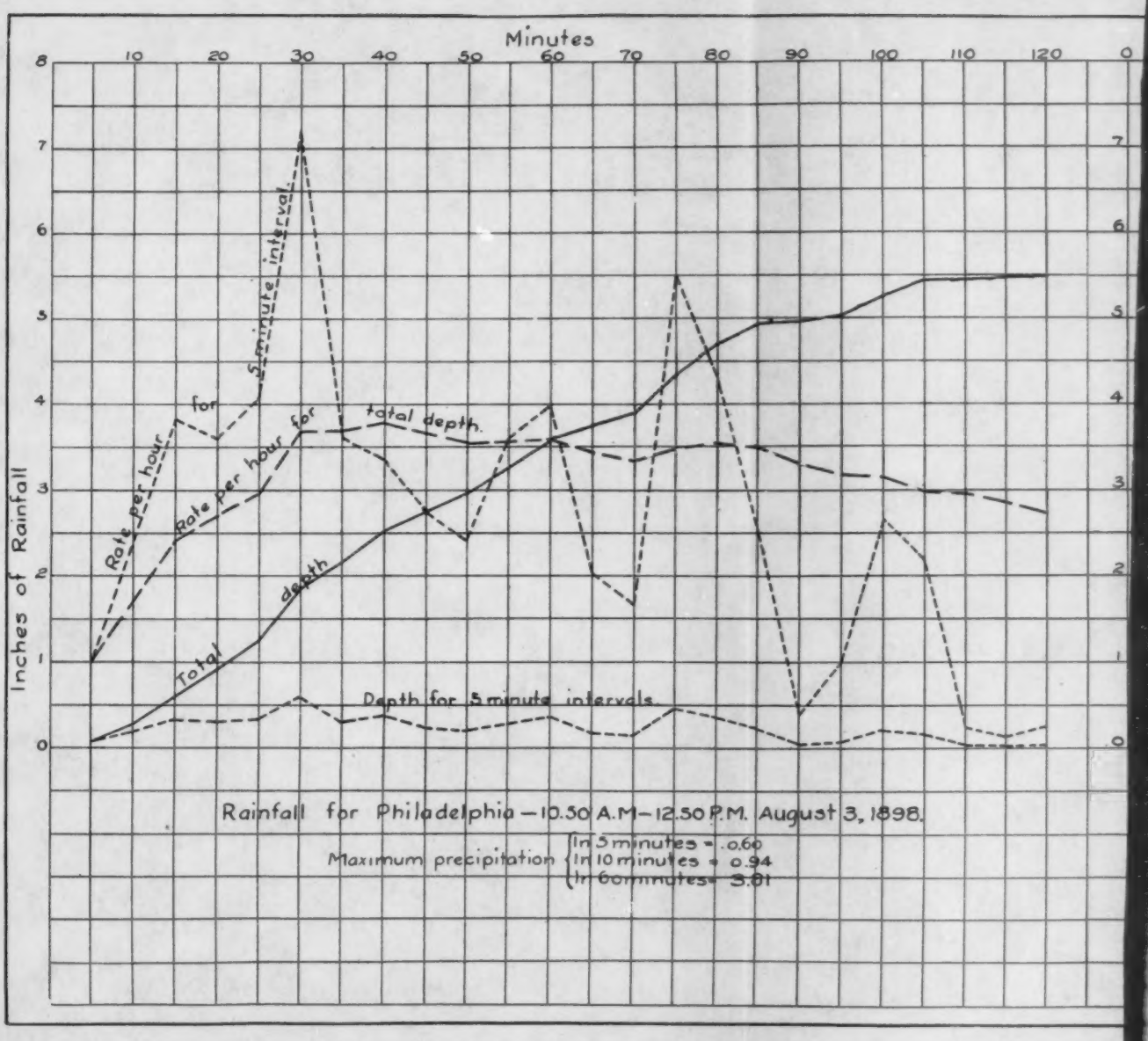
Rainfall at Escanaba, Mich. July 21, 1903. 12.35 P.M. to 1.10 P.M.

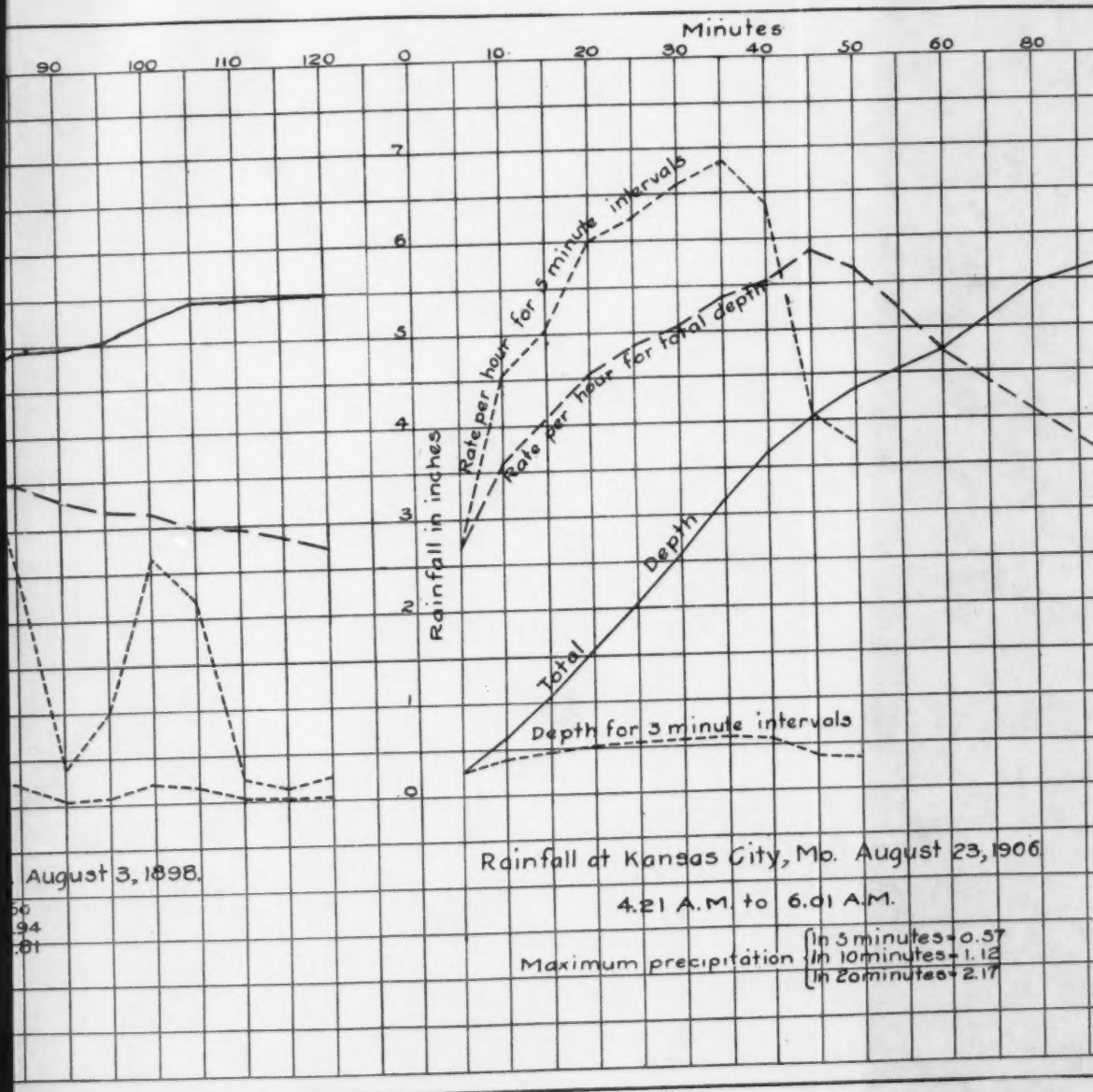
Maximum Precipitation
In 5 minutes = 0.69
In 10 minutes = 1.32
In 15 minutes = 1.52

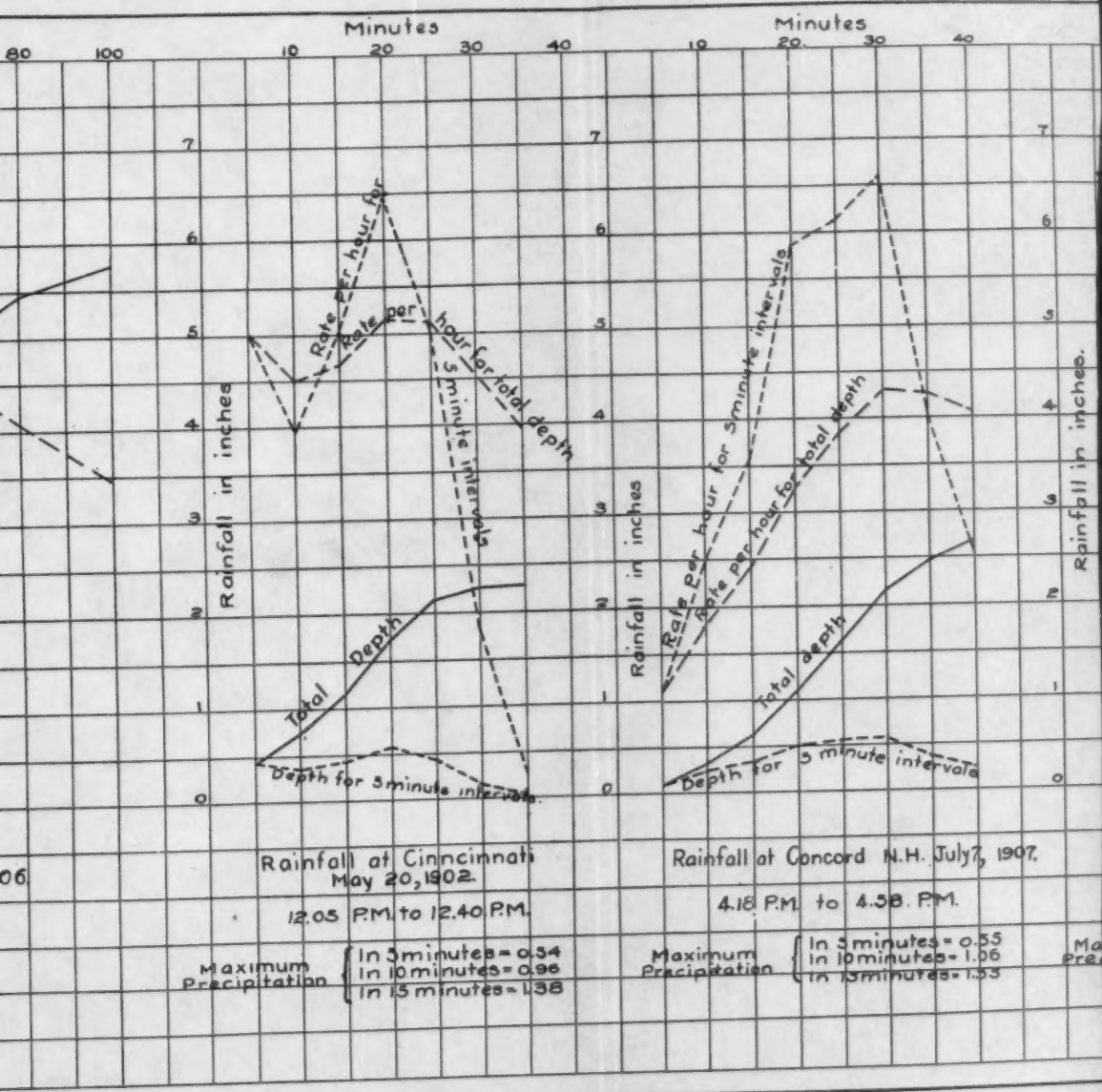
Rainfall at Baltimore Md. July 12, 1903.

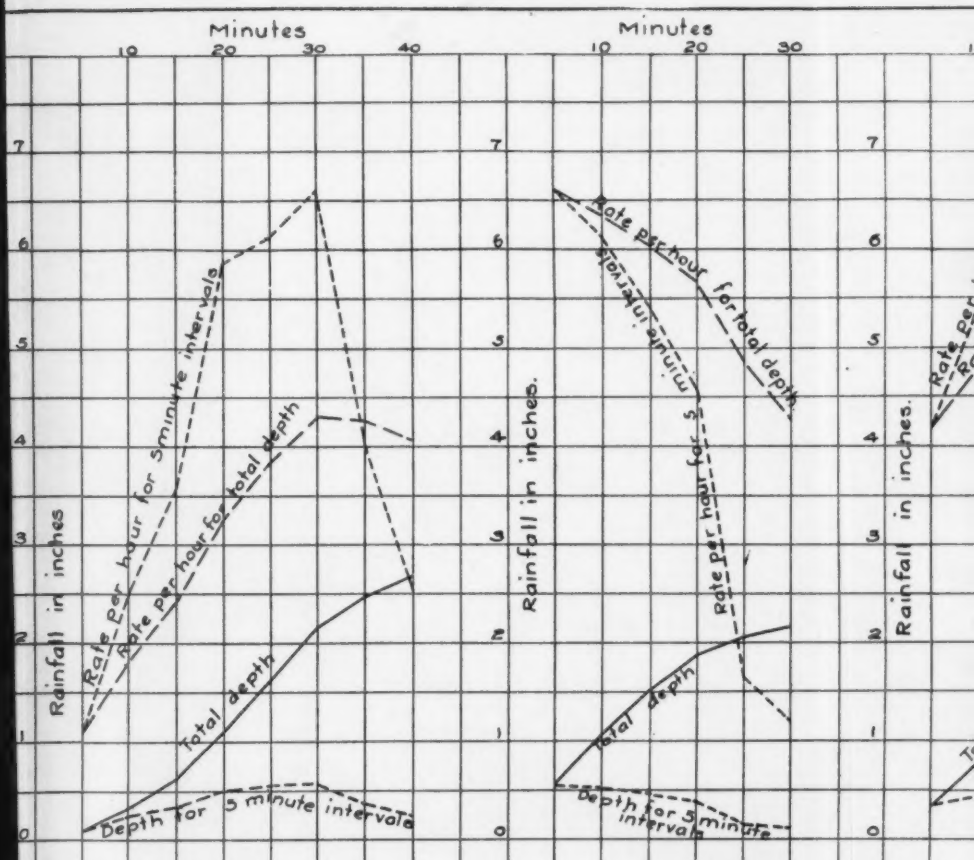
Maximum Precipitation
In 5 minutes = 0.80
In 10 minutes = 1.39
In 15 minutes = 1.92.

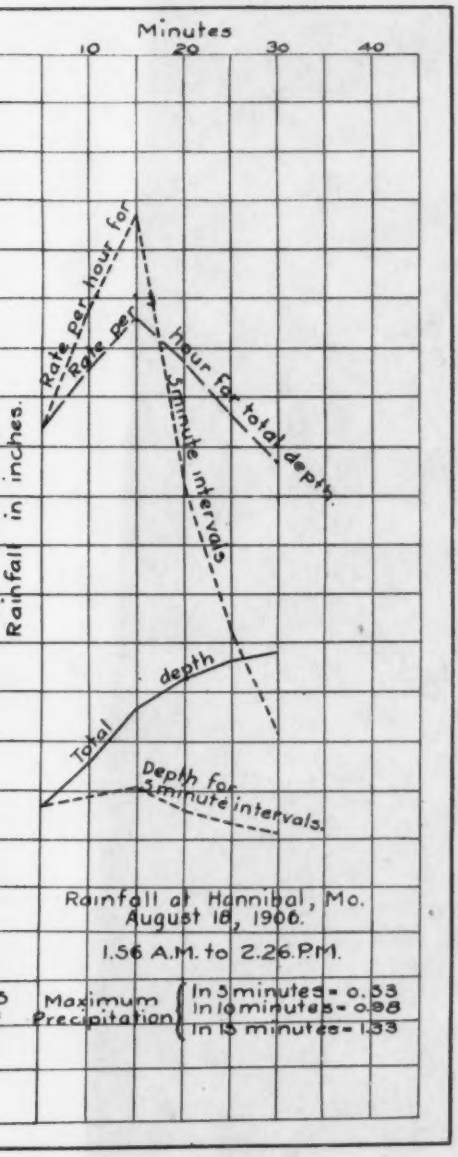
PLATE 12


Minutes
10
20
30
40
50
60
70
80
90
100
110
120
0
Inches of Rainfall
0
1
2
3
4
5
6
7
8
Rate per hour for 5 minute interval
Rate per hour for total depth.
Total depth
Depth for 5 minute intervals.
Rainfall for Philadelphia – 10.30 A.M – 12.50 P.M. August 3, 1898.
Maximum precipitation
In 5 minutes = .060
In 10 minutes = 0.94
In 60 minutes = 3.81


Minutes
90
100
110
120
0
10
20
30
40
50
60
80
7
6
5
4
3
2
1
0
Rainfall in inches
Rate per hour for 5 minute intervals
Rate per hour for total depth
Total Depth
Depth for 3 minute intervals
August 3, 1898.
Rainfall at Kansas City, Mo. August 23, 1906
4.21 A.M. to 6.01 A.M.
Maximum precipitation
In 5 minutes = 0.57
In 10 minutes = 1.12
In 20 minutes = 2.17


Minutes
80
100
10
20
30
40
Rainfall in inches
Rate per hour for 5 minute intervals
Rate per hour for total depth
Total Depth
Depth for 5 minute intervals
Rainfall at Cincinnati
May 20, 1902.
12.05 P.M. to 12.40 P.M.
Maximum Precipitation
In 5 minutes = 0.34
In 10 minutes = 0.96
In 15 minutes = 1.38
Minutes
10
20
30
40
Rainfall in inches
Rate per hour for 5 minute intervals
Rate per hour for total depth
Total depth
Depth for 5 minute intervals
Rainfall at Concord N.H. July 7, 1907.
4.18 P.M. to 4.38 P.M.
Maximum Precipitation
In 5 minutes = 0.55
In 10 minutes = 1.06
In 15 minutes = 1.55


Minutes
10
20
30
40
Rainfall in inches
Rate per hour for 5 minute intervals
Rate per hour for total depth
Total depth
Depth for 5 minute intervals
Minutes
10
20
30
Rainfall in inches.
Rate per hour for 5 minute intervals
Rate per hour for total depth
Total depth
Depth for 5 minute intervals
Minutes
10
20
30
Rainfall in inches.
Rate per
Rainfall at Concord N.H. July 7, 1907.
4.18 P.M. to 4.58 P.M.
Maximum Precipitation
In 5 minutes = 0.55
In 10 minutes = 1.06
In 15 minutes = 1.53
Rainfall at Lynchburg Va, August 29, 1903
Between 9.00 P.M & 10.00 P.M.
Maximum Precipitation
In 5 minutes = 0.35
In 10 minutes = 1.06
In 15 minutes = 1.51



Rainfall at Hannibal, Mo.
August 18, 1900.

1.56 A.M. to 2.26 P.M.

Maximum Precipitation	In 5 minutes = 0.53	
	In 10 minutes = 0.98	
	In 15 minutes = 1.33	

PLATE 13

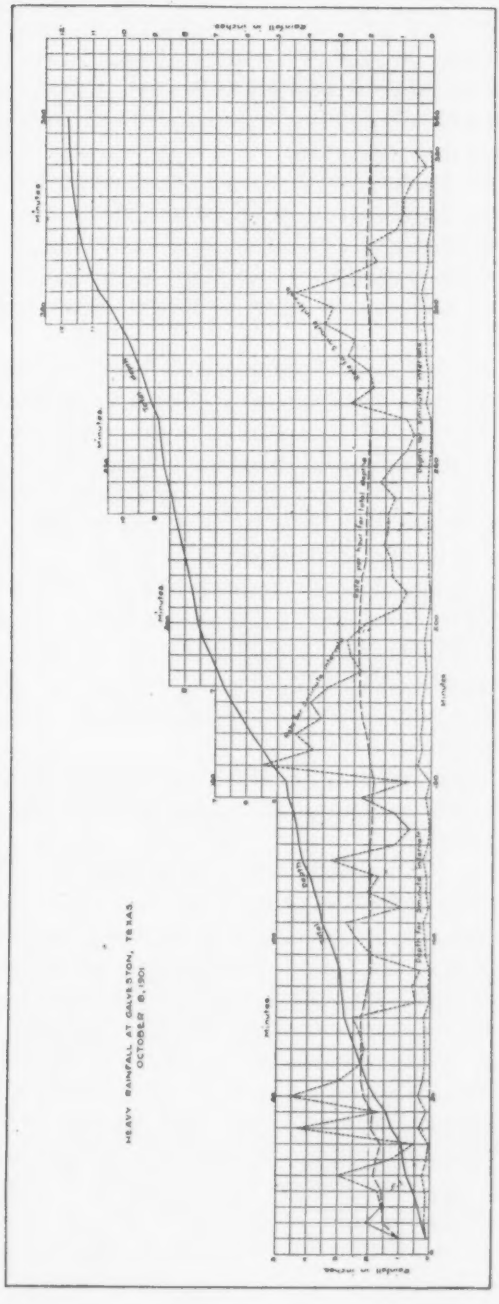

HEAVY RAINFALL AT GALVESTON, TEXAS
OCTOBER 9, 1901
minutes
Rainfall in inches

PLATE 14

The character of the watershed is an important element in such runoff calculations, for it is not a mere theory to state that configuration and topographic features of a small watershed may produce higher runoffs from 2 inches in 40 minutes than the same amount in 30 minutes, but of course each case is individual. Protection or automatic provision is required to meet these, for such storms occur with little warning, and their rapid culmination offers no opportunity for opposing flood conditions as they approach. Not only is ample discharge capacity for reservoirs demanded, but pumping equipment adjoining streams must be located above lines of flood damage.

A 50 per cent runoff does not seem excessive for a severe storm, but this proportion from a downpour of 1½ inches in 30 minutes equals 968 second feet from each square mile, or 1½ second feet from every acre. (This is the estimated maximum runoff from Mill Creek watershed at Erie on August 3, 1915.) Civic engineering has given much attention to the disposal of the high runoff which results from intense storms falling on areas largely impervious.

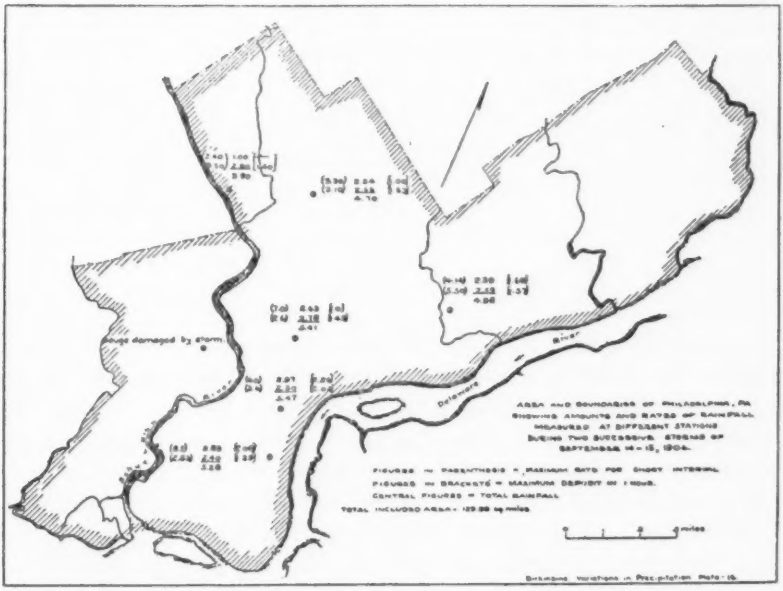
Irregular frequency of severe storms is illustrated by Kansas City, Missouri, which in September, 1914, received 16.17 inches of which 92 per cent fell in 4 storms, and 43.5 per cent in one rain. Rockport, Massachusetts, had 10.77 inches of rain in July, 1911. There were 7 days with rain, 2 of which supplied nearly 70 per cent of the total deposition.

An intense storm, on July 15, 1914, covered an area of 30 square miles in Pennsylvania, and produced severe flood conditions on a dozen small streams.

May 4 and 5, 1902, a cloudburst over a large area in Oklahoma caused destruction to life and property at Foss. The excessive rain continued 40 minutes, and much damage was done at Guthrie, which received 4 inches in the 2 days, whereas the normal total for May is 3 inches. On the 22nd Guthrie received 2.2 inches as its share of a severe rain which gave for the 21st and 22nd totals of 2.13 inches to 8.17 inches, the average 2 day total for the 12 stations equalling 4.55 inches. During this storm, between Fort Reno and Oklahoma City a rectangular trough, 10 inches deep and in an exposed location, was entirely filled and probably overflowed between night and morning.

At Philadelphia, Pennsylvania, in mid-September, 1904, 2 intense storms 7 hours apart, gave three-quarters of the total deposition for the month, and these severe downpours were felt over a large

area of the city. On plate 16 are shown the rainfalls recorded at 6 rain gauges in the city during these 2 storms, one being an official Weather Bureau Station and the others maintained by the Bureau of Surveys. Unfortunately another pluviometer was put out of commission by the first storm, so that the severity could not be determined, but it must have been unusual. The area within the city boundaries is nearly 130 square miles, and though the entire territory was not covered with gauges, the total quantities recorded for the 2 storms at the different stations, which ranged from 9,060,000 to 12,600,000 cubic feet per square mile, illustrate the vast quantity

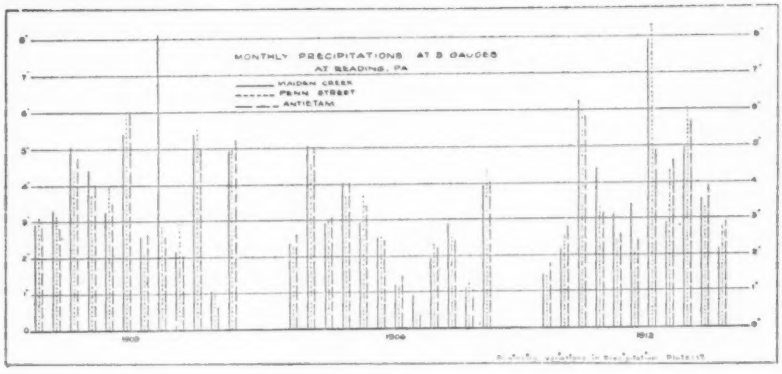


of water which fell. Other severe storms show similar variation in entire amounts and maximum short-time intensities, the differences between two of these stations in some instances being very extreme, a condition that would be expected of intense storms over such an extended area.

Even in small distances the inequality of rainfall received during such storms is material. Records of adjoining gauges show the major differences in the season of torrential rains, and the inequalities are frequently very large. The daily records of rainfalls given on plate 17 show that the extreme discordance of the totals for

August 1906, and July 1912, were due to such conditions.[2] Severe storms in close succession are frequent in the more southern humid regions. Studies of records of excessive precipitation for different locations illustrate the inconstancy of this feature, both in intensity and frequency.

Instances are given in Table 6.



THUNDERSTORMS

Precipitation from thunderstorms is experienced over a large portion of the country, the location of maximum frequency being in Florida, and the lower Mississippi Valley, and the least susceptible district, the Pacific and New England coasts. Localities near high mountains are subject to many such storms, often of unusual severity. In the arid regions thunderstorms occur, but generally the rain is evaporated in transit, little or no water reaching the earth, and "dry thunderstorms" are at times recorded at other localities.

The severe electrical storm of August 16, 1914, near Tonapah, Nevada, was without any precipitation. Santa Fé, New Mexico, had for the period 1904–1913 annual averages of 73 days with thunderstorms, 96 days with precipitation, and 14 inches of precipitation; and the year 1910 had 76 days with thunderstorms, 75 days with rain, and a total of 8.65 inches of water.

Professor Humphreys has shown that, being caused by rapid vertical convection of humid air, the genesis of thunderstorms is either by excessive insolation, or by a layer of air being overrun by

[2] These three gauges are separated by distances of 6.28, 6.12 and 2.82 miles.

TABLE 6

Records of some severe storms

LOCATION	DATE	DEPTH IN INCHES	DURATION		AVERAGE RATE PER HOUR
			Hrs.	Min.	
Albany, N. Y.	July 10, 1876	1.12	0	10	6.72
Alpena, Mich.	September 20, 1884	1.05	0	11	5.73
Amanda, Ia.	July 31, 1878	1.56	0	15	6.24
Atlanta, Ga.	April 24, 1889	1.12	0	10	6.72
Atlanta, Ga.	July 23, 1898	4.30	0	51	5.06
Berne, Ind.	August 16, 1913	2.55	0	30	5.10
Biscayne, Fla.	March 28, 1874	4.10	0	30	8.20
Brandywine Hundred, Pa.	August 5, 1843	10.00	2	0	5 00
Cambridge, Ohio.	July 16, 1914	7.09	1	30	4.73
Catskill, N. Y.	July 26, 1819	18.00	7	30	2.40
Chicago, Ill.	May 25, 1896	1.24	0	15	4.96
Collinsville, Ind.	May 23, 1888	1.70	0	12	8.50
Concord, Pa.	August 5, 1843	16.00	3	0	5.33
Embarrass, Wis.	May 28, 1881	2.30	0	15	9.20
Flatbush, L. I.	August 22, 1843	9.00	8	0	1.12
Ft. Leavenworth, Kan.	July 21, 1887	1.90	0	20	5.70
Ft. McPherson, Neb.	May 27, 1868	1.50	0	5	18.00
Ft. Randall, S. D.	May 28, 1873	1.56	0	15	6.24
Ft. Scott, Kan.	October 2, 1881	1.80	0	20	5.40
Galveston, Tex.	June 4, 1871	3.95	0	14	16.93
Huron, S. D.	July 26, 1885	1.30	0	10	7.80
Indianapolis, Ind.	July 12, 1876	2.40	0	25	5.76
Jewell, Md.	July 27, 1897	14.75	18	0	0.82
Lebanon, Pa.	July 10, 1914	5.00	2	0	2.50
Long Branch, N. J.	July 14, 1912	0.80	0	5	9.60
Newton, Pa.	August 5, 1843	5.50	0	40	8.25
Newton, Pa.	August 5, 1843	13.00	3	0	4.33
New York, N. Y.	May 22, 1881	1.15	0	10	6.90
New York, N. Y.	November 18, 1886	0.25	0	2	7.50
Osage, Ia.	August 26, 1881	1.40	0	15	5.60
Ottawa, Ohio.	August 21, 1913	2.28	0	40	3.42
Palmetto, Nev.	August 7, 1890	8.80	1	0	8.80
Paterson, N. J.	July 13, 1880	1.50	0	8	11.25
Philadelphia, Pa.	September 12, 1862	9.00	5	0	1.80
Portsmouth, Ohio.	June 22, 1851	1.75	0	15	7.00
Sandusky, Ohio.	July 11, 1879	2.25	0	15	9.00
San Francisco, Cal.	December 20–21, 1866	7.76	8	45	0.89
St. Louis, Mo.	August 15, 1848	5.05	1	0	5.05
Stroudsburg, Pa.	August 1, 1913	7.50	3	50	1.96
Tridelphia, W. Va.	July 19, 1888	6.90	0	55	7.53
Washington, D. C.	July 26, 1885	0.96	0	6	9.60
Worthington, Minn.	August 20, 1913	8.00	11	0	0.73

a sufficiently colder strata, the cause of ocean thunderstorms and of some on land, or by a saturated body of air being underrun and lifted by a denser layer. Consequently, land thunderstorms are most frequent in the latter portion of the afternoon, while those on the oceans more often occur shortly after midnight. He also mentions five barometric conditions with whose occurrence thunderstorms are likely. These are (a) high temperatures of nearly uniform pressure over large areas, causing heat thunderstorms; (b) cyclonic storms; (c) a barometric valley enclosed in a "V" shaped cyclonic isobar, occurring in a region of tornadoes and often termed tornadic thunderstorms; (d) a trough of low pressure between two areas of high pressure, these he terms anticyclonic or trough thunderstorms, and (e) the boundary between warm and cold waves, designated as border thunderstorms.

Current opinion often holds that thunderstorms follow valleys, but notation of paths of such storms indicates that they are produced at too great a height to be affected by minor topography, though the predominance of moist air in watered valleys may contribute to their formation in such places.

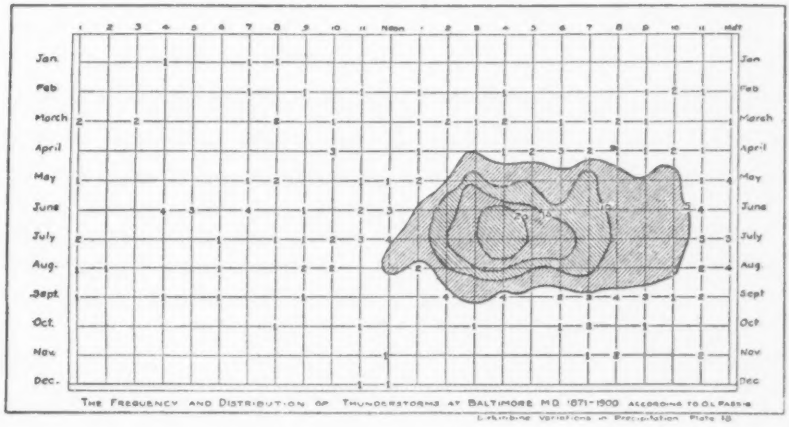
Reference to records indicates that winter thunderstorms are more common than is generally supposed, but as they lack the intensity and duration of the thunderstorms of summer and seldom bring hail, they frequently pass unnoticed, especially when occurring at night. They are credited to cold air over-running a stratum of relatively warm air, and are most common adjacent to the Atlantic and Gulf coasts with increasing frequency at lower latitudes.

Prof. Oliver L. Fassig's chart of hourly and seasonal occurrence of thunderstorms at Baltimore, Maryland, is reproduced by permission on plate 18, and clearly illustrates the predominance of heat thunderstorms at the time the earth's surface has become well warmed by continued insolation.

Messrs. Cox and Armington have pointed out that the predominance of May thunderstorms in Chicago at about 4 a.m. is due to the alternation of lake and land breezes, as the wind from the Lake reaches a maximum about this hour, at a season when the general temperature is rapidly increasing; while the maximum occurrence of ocean thunderstorms is in the early morning hours, when the difference between surface and air temperatures reaches a maximum and encourages rapid vertical convection.

As affecting the occurrence of rain the thunderstorm is in many

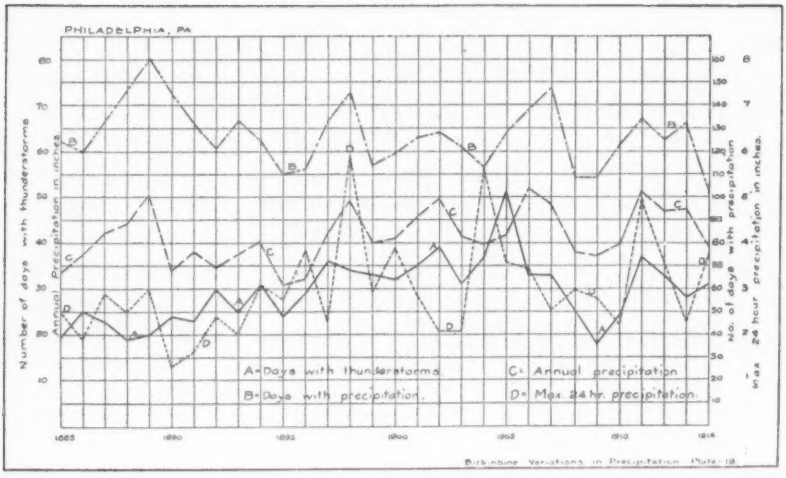
localities an important factor, for it may furnish the majority, or even all the rainfall during periods of deficient precipitation. Much of the summer rainfall of New Orleans occurs with thunderstorms, and other Gulf and South Atlantic regions have recorded in some years over 100 thunderstorms per annum, the majority in June, July and August, when two or more thunderstorms in one day are of frequent occurrence. The summer rainfall in the lower elevations of Arizona is almost entirely due to thunderstorms. Other localities, extending well to the north, receive most of their summer rain by thunderstorms. While many thunderstorms are local, meteorological conditions may produce large areas of thunderstorms, as in Missouri and southern Illinois, May 25 and 26, 1893.



THE FREQUENCY AND DISTRIBUTION OF THUNDERSTORMS AT BALTIMORE MD. 1871-1900 ACCORDING TO DIURNAL VARIATIONS OF PRECIPITATION Plate 19

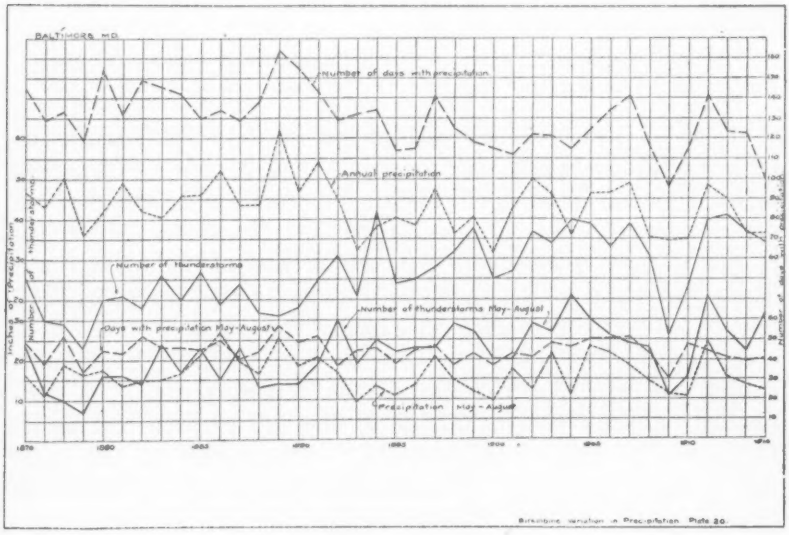
Plates 19, 20 and 21 indicate for several localities how the frequency of thunderstorms and the total quantity of water deposited follow a similar trend in the majority of years, while the years of disagreement illustrate in a general way the relative effect of thunderstorms with heavy downpours, as well as those of slight or no rain. These variations are illustrated in plate 22, plotted from Mr. J. H. Spencer's tabulation of data for Lincoln, Nebraska.

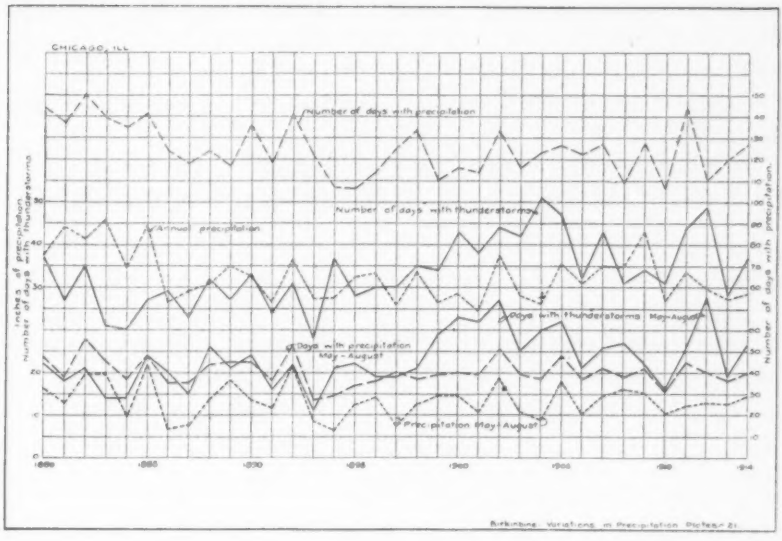
A relation between warm temperatures and frequency of thunderstorms can be expected, especially in humid regions. A more marked tendency to synchronism is illustrated by the curves for the period of major occurrence of thunderstorms on the lower field of plates 20 and 21. The Baltimore record is of the number of thunderstorms, the others of number of days with thunderstorms.



It should be noted that the thunderstorm records maintained by the Weather Bureau properly note all thunderstorms, whether or not any rain occurs, though formerly only thunder with rain was recorded.

As with many other precipitation records, the exceptions are lost in the average of a large number of records, as shown on plate 23, after a diagram accompanying Professor Humphreys' article on

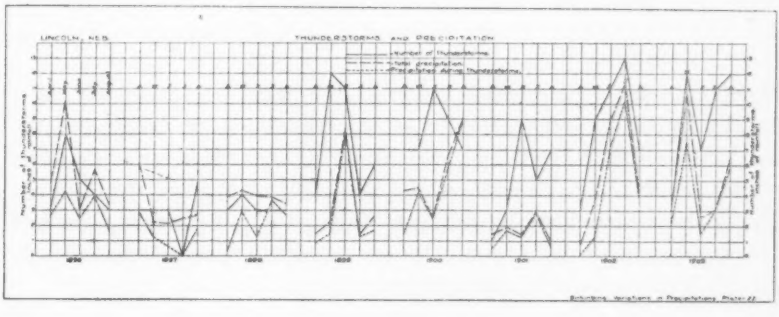




"The Thunderstorm and its Phenomena," and in which he states that the relation is substantially similar for the areas east and west of the 100th meridian, though the climates of these two districts are so radically dissimilar.

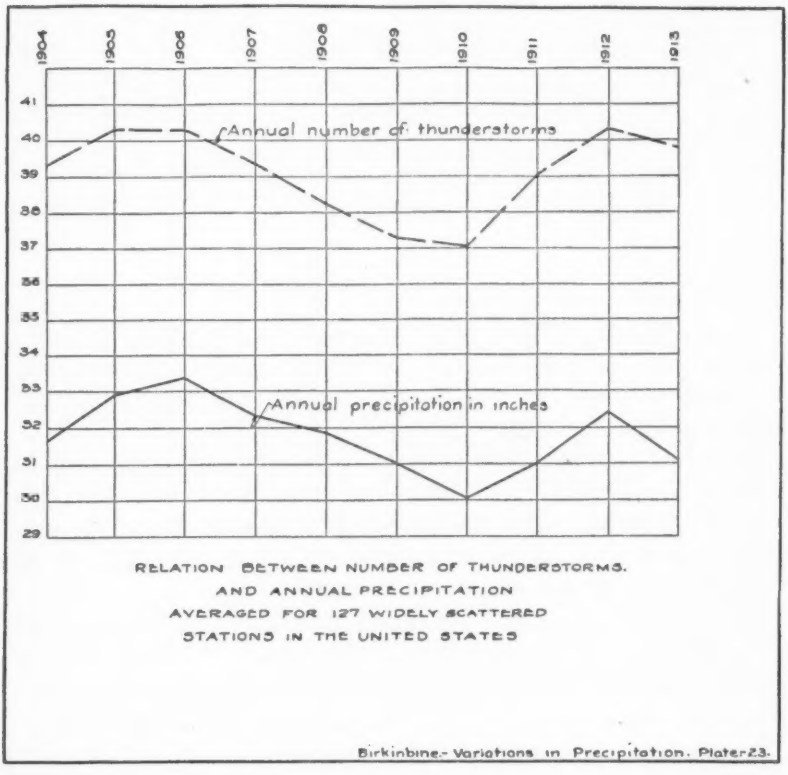
Prof. Humphreys used records subsequent to 1904 only, so as to have data on a uniform and reliable basis, for he was unable to justify the remarkable increase in records of thunderstorms between 1890 and 1904, although he referred to a keener observance of meteorological phenomena in later years.

Some investigators have noted a tendency to periodic cycles in the occurrence of thunderstorms, which may be traced on the various diagrams of occurrence, and which is suggested by records



of thunderstorms at other locations. Being due to meteorological causes it is expected that this feature would vary in a general way with other conditions, and be most frequent in warm periods, and the cycles accordingly display nonuniformity in occurrence and magnitude.

As affecting water supply the thunderstorm is less satisfactory, by reason of the severity with which the water falls, causing high



RELATION BETWEEN NUMBER OF THUNDERSTORMS. AND ANNUAL PRECIPITATION AVERAGED FOR 127 WIDELY SCATTERED STATIONS IN THE UNITED STATES

Birkinbine:- Variations in Precipitation. Plate 23.

runoff and little percolation, increased erosion and turbidity, and possibility of damage not only to structures but to existing water mains in soil subject to saturation from overflowing stream channels or storm sewers. The remarkable rainfall of August 3, 1898, at Philadelphia, see plate 13, occurred during the most severe electrical storm recorded there, and all the severe rains noted on plates 11 to 13 occurred during thunderstorms.

Many other torrential rains take place during thunderstorms, and such are marked by more pronounced irregularity of rate of deposition and unusual intensity during some of the brief intervals. However, the quantity of precipitation is not to be measured by the violence of the hail or wind, especially in tornadic thunderstorms, for the thunderstorm squalls have furnished many of the destructive winds. Many have noted the more intense rain which we observe after a lightning flash, although it is the excessive condensation of rain in the storm cloud which creates the electric discharge; and Mr. William A. Bentley's investigation of rain drops showed large drops to be more frequent during the occurrence of electrical storms. These last two features tend to compact the earth, for the velocity of falling rain drops may reach 25 feet per second, and consequently the direct runoff is increased.

FROZEN PRECIPITATION

Hail, which is an adjunct of thunderstorms, has fallen in excess quantities at a number of locations, depths of more than a foot having been noted in the Middle and North Atlantic region. Because of the high water content, its occurrence in the early stages of a thunderstorm, the probable immediate sequence of torrential rains, and the warm temperature of the season, unusual deposition of hail may cause a high runoff. In such cases the quantity is of more import than the size of individual hail-stones or agglomeration of these into large lumps. Fragile apparatus is to be protected against hail, and where electrical equipment is in service the layout should be such that windows broken by hail will not allow the subsequent hard wind-driven rain access to electrical apparatus that would suffer damage or be eliminated from service by water.

Sleet, frozen raindrops, or rain freezing as it falls, ice storms, which sometimes occur in intermittent succession so that they are practically in combination, tend to form an impervious coating on the soil or on snow, and these permit quick runoff from subsequent rain. Ice storms, by the heavy coating deposited on trees and wires, have frequently interrupted electrical service, and there are instances of the supporting poles or towers being broken or pulled awry. Automatic flashboards, exposed operating devices for gates, etc., are seriously hampered by such an ice covering.

Plate 24 reproduces an instance of damage from an ice storm over a moderate area. The effect is illustrated by the fact that a small

twig carried 27 times its weight of ice. A study of 211 storms showed a sleet thickness of less than $\frac{1}{4}$ inch for 42.6 per cent; from $\frac{1}{4}$ to $\frac{1}{2}$ inch for 29.4 per cent; from $\frac{1}{2}$ inch to 1 inch for 19.9 per cent and more than 1 inch for 8.1 per cent.

The destruction by a combination of snow, rain and ice storms affected about 600 square miles, and measurements showed branches $\frac{1}{4}$ inch thick entirely surrounded with a thickness of 1 to $1\frac{1}{2}$ inch. At Phillipsburg, New Jersey, this storm extended through 98

hours, and the range of temperature in this entire interval was but 6°F., and there was little wind to aggravate conditions.

Temperature conditions of the different air strata are an important factor in precipitation rates, for many hail-stones are melted into raindrops, or even evaporated before reaching the earth; while condensed moisture is frequently frozen in transit.

The sleet and ice storms of the Upper Ohio region in March 1912, covered an area 75 miles wide and 450 miles long, and those in Eastern Pennsylvania, in 1914, were marked in some localities by a narrow path and by spots of severity.

SNOW

Snow usually steadies the runoff as the melting deposit feeds the ground, especially when, as occasionally occurs, the snow blanket falls before the ground freezes.

Freshly fallen snow contains from 3 per cent to 14 per cent of water, as it varies from the dry feathery type to that of a soft wet character, and much of the falling snow can be included in the range of from 8 per cent to 12 per cent of water. But snow on the ground acquires a higher moisture content, due to compaction by weight of the upper portions, absorption of heat radiated from the earth, melting of the upper layers by sun and by mild temperature, and by absorption of moisture from humid air. Actual tests have shown laid snows to have water equivalent from 20 per cent to 60 per cent and it is the actual water content rather than the depth of snow which is important.

In the warmer regions of rare snow its occurrence in quantity is likely to have an appreciable effect on water supply, for the snow deposited is in such cases quickly melted and may create high runoff conditions. Some snow has been reported over nearly all the United States, but slight flurries, or even several inches depth, do not contain sufficient water to seriously affect runoff.

Snow in considerable quantity is reported to have fallen at Charleston, Savannah, Mobile and Pensacola in 1866; other southern instances being, 4 inches at New Orleans (1852), 5 inches at Montgomery, Alabama, December 29–31, 1880, and on the same date nearly 2 inches at Rio City, Texas; while Memphis, Tennessee, received 18 inches of snow on March 16 and 17, 1892. Mr. C. F. Volney mentioned a 5-foot snowfall at Norfolk on February 4, 1798.

Over much of the areas which experience some snow each winter the occurrence, distribution and the amount show a greater range than rainfall records, for temperature conditions determine the character of precipitation. In 1914 the total precipitation at Columbus, Ohio, was four-fifths the normal, but the snowfall was 50 per cent above mean, while Indianapolis, Indiana, had a total precipitation that was three-fourths the normal, and the second lowest yearly record, but the snowfall was nearly twice the average and the second highest annual.

The Christmas snowstorm of 1909 was described as the most severe over a large area in a half-century. Nearly all sections

from the Missouri River to the Atlantic Ocean, except New England where the snow fell on the 26th, received rain or snow on the 25th, the southern boundary of snow passing through Wilmington, North Carolina, and Augusta, Georgia, thence south of Birmingham, Alabama, and Vicksburg, Mississippi, and north of New Orleans and Galveston. The maximum deposits occurred in Pennsylvania and Delaware, where the average depth was 20 inches.

On January 10 and 11, 1905, 6 inches to 30 inches of snow occurred in 15 states, and on April 3, 1915, a snow storm extending along the Middle Atlantic Coast gave an average of 19 inches, an April record, at Philadelphia, Pennsylvania. Mr. Charles Pierce noted a 3-foot snowfall for this locality on April 19, 1741, but verification of the accuracy of this record is lacking.

Springfield, Missouri, in the winter of 1911–1912 had 53.1 inches of snow, the 20 inches which fell on February 20, 1912, exceeding any previous monthly record for 25 years, and being greater than most annual totals. At Grantville, Maryland, the snow from October, 1910, to the following April inclusive, totalled over 100 inches, and Blue Knob, Pennsylvania, had 96 inches of snow in December, 1890.

Mountain regions with their heavier precipitation, where exposed to humid winds, receive larger quantities of snow, which owing to the cooler temperature, and often on account of shading by forests, melt slowly. The west and northwest offer examples of a summer supply of water from slowly melting mountain snow, and northern locations in other regions illustrate a generally non-excessive and well sustained spring runoff, due to the tardy melting of snow in well wooded districts. While the large catchment surface of trees holds much snow from reaching the ground and exposes this snow to the sun and air, these same branches shelter the forest floor.

Where part or all of the drainage area of a water supply lies in mountain land, consideration must be given to the deeper snows on the higher elevations. Moist clouds passing over a valley or moving up a slope may not be precipitated until the higher elevations are reached. But a distinct snow line, or a demarcation between snow deposits of materially different depth, is not always confined to the higher mountains. On a mountain drainage area in Lycoming County, Pennsylvania, the higher topography was but 500 feet above the valley plane, but the line of ice storm and deeper snow, 3 to 4 feet against but 15 inches to 18 inches a short distance below, was plainly marked along this and the neighboring hills.

An interesting case of snowfall distribution exists in New York State and is shown on plate 27, which gives variations in annual quantity and apportionment, and the relation between annual snowfall and precipitation. In February 1911 two localities in this State recorded 47 inches and 55 inches of snow, and at the latter place 48 inches fell the following month, while the snowfall at Adams, November 1900, to April 1901, totalled 334.5 inches, of which 96 inches was accounted for in February.

Especially unfavorable is that type of snow called a "blizzard," for though the actual depth of snow is often moderate, damages or inconveniences are caused by the high drifts formed.

The Chicago records indicate no fixed relation between the quantity of snow and the *mean* winter temperature. While the maximum seasonal snowfall since 1884 occurred in the coldest winter, a nearly equal quantity was measured when the mean temperature was above normal, and though the minimum recorded depth fell in a severe winter small amounts have been noted in warm winters.

Mr. C. F. Brooks gives to February the average maximum monthly snowfall on the Atlantic Coast, and the same month which is the coldest, in the Ohio Valley; but for the upper Mississippi Valley the maxima are in December and March.

Mr. Chas. A. Mixer, C.E., took a sample of snow on the ground, which was 38 inches deep and contained 27.6 per cent of water while 10 days later the depth was but 20 inches and the water content 49.2 per cent.

Mr. H. S. Cole measured drifts in Nevada at 9000 feet elevation, and obtained a sample 14½ feet deep with 46 per cent of water, and one of 13½ feet containing 38.4 per cent.

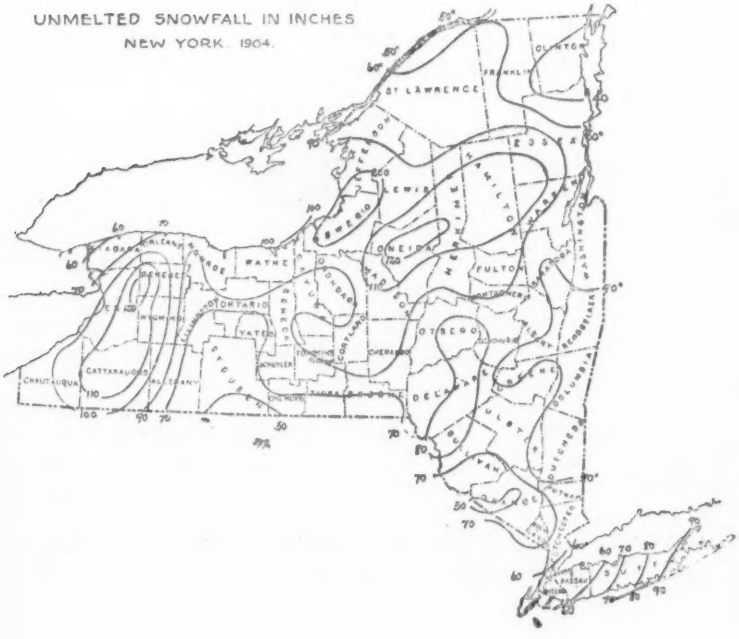
The measurements of Messrs. Thiessen and Alter of snow on the ground in the mountains of Utah, include the following average results:

Maple Creek Canon, average depth of samples, from 23 inches to 52 inches; per cent of water, from 22 to 35. In one case on a steep slope 24 per cent.

1911, average depth.....35 inches, 31 per cent water
1912, average depth.....42 inches, 24 per cent water
1913, average depth.....48 inches, 25 per cent water

Measurements in Big Cottonwood Canon of snow at various locations, and thicknesses ranging up to 9 feet, showed a water equiva-

Birkinbine Variations in Precipitation. Plate 27

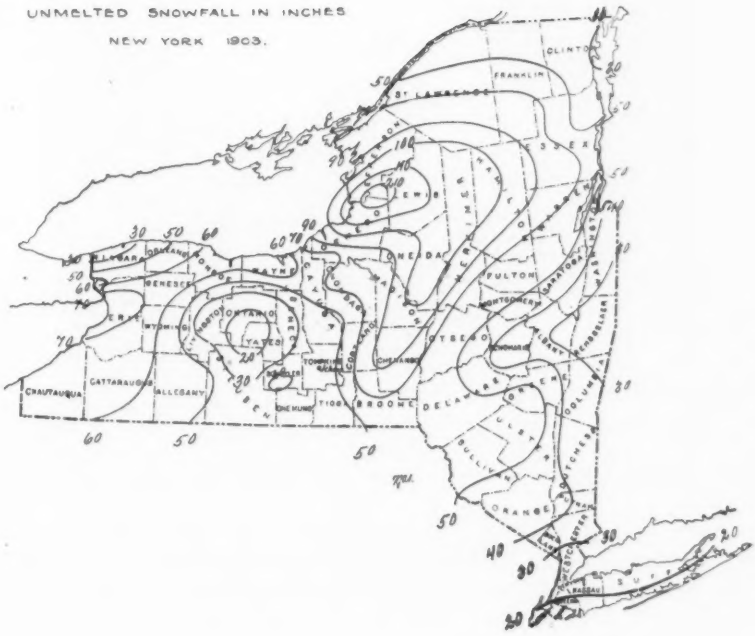


UNMELTED SNOWFALL IN INCHES, 1909.

NEW YORK

UNMELTED SNOWFALL IN INCHES

NEW YORK 1903.



lent ranging from 33 per cent to as high as 48 per cent, and one measurement $11\frac{1}{2}$ feet deep in a snow slide gave 56 per cent. The water equivalent for the entire watershed of 48.5 square miles was 21.5 inches in 1912, and 12.26 inches in 1913.

SWATH CUT BY SNOW SLIDE IN COLORADO FOREST.

Courtesy of 'FOREST LEAVES'

Birkinbine. Variations in Precipitation. Plate-28.

Slides not only bring down suddenly large quantities of snow, but also much debris to fill and clog any basin or watercourse below. The destructive action of large slides is illustrated by plate 28.

Mr. Alter states that snow lying late in the mountains becomes almost ice, and carries from 50 per cent to 75 per cent and even as high as 85 per cent water. Other measurements have shown snow on the ground carrying from one-fifth to one-third water, the quantity being less in shaded localities.

Mr. B. F. Eliason's measurements on the Pole Creek watershed in Utah, in April 1913, gave averages of 27 per cent to 32 per cent of water for depths ranging between 18 inches and 33 inches. Mr. R. R. Briggs, in March 1913, found an average content of 33 per cent for 15 inches to 20 inches on the high plateaus between the Salt and Little Colorado watersheds in Arizona.

Mr. A. C. McAdie has compiled interesting data concerning the snowfall at Summit, California, elevation 7017 feet, where 86 per cent of the precipitation occurs as snow, and the rainfall is mainly from July to September. These showed in 42 years a total seasonal precipitation varying from 80.1 inches to 21.8 inches of water, maximum monthly 30.40 inches in April 1880, and February 1904; and snowfall, 34 years' record, 783 inches to 153.5 inches, average 443.5 inches, with 298 inches for April 1880. Minimum monthly snowfalls recorded were January 1 inch, April 0.4 inch, December 0.2 inch, and for the other months zero. This location receives the greatest seasonal snowfall recorded in the states. Mr. A. H. Palmer gives the average annual totals as 420 inches of snow and 48 inches of precipitation.

A test of the water content of laid snow at different depths at Summit, gave,

At the surface	34 per cent
At 64 inches depth	45 per cent
At 174 inches depth	59 per cent

Where winters are severe a deep accumulation of snow is often formed after water surfaces are frozen over, giving large quantities of moisture to augment the direct runoff and rainfall when this occurs, and creating a brief but heavy discharge.

On small drainage areas which permit quick concentration of runoff, snows on ice or on frozen ground and melted by warm rains, have produced many extreme floods though of brief duration. The Port Neuf and Blackfoot Rivers in Southeastern Idaho were in flood in January, 1911, when heavy rain and warmth melted new snows lying on former deposits, which previous rain and cold had covered with ice, giving quick runoff.

The majority of floods from melting snow in the warmer regions have been on streams whose head-waters lie in mountain ranges; and recorded floods due to melting snow alone, or combined with rainfall, are more frequent in regions with annual occurrences of material snowfall, because of the larger quantities of the frozen moisture. Melting snow alone produced a severe and damaging flood at Barre and Montpelier, Vermont, in April, 1912. An average on the watershed of one-third inch of rain, with snow melted by warm air, occasioned the severe flood on the Grand River, Michigan, in the spring of 1904, and a similar condition brought about high water on the Mohawk River in the same season. But in less moderate regions, or similarly, when occurring in or just previous to mild weather at other localities, the rapid melting brings a quick runoff, often severely intensified by rain.

Mr. Mixer prepared some interesting charts of the relation between snow and rain on the watershed, and stream flow at Rumford Falls, Maine, which clearly illustrates the effects of a moderate warm rain and melting snow in increasing the river discharge, in April 1901, and the absence of the usual spring freshet the following year, because the ground was bare when the hard rains occurred.

The March 1907, flood at Pittsburgh, Pennsylvania, was due to a rainfall of about 2 inches in 2 days, and warm temperatures following snowfall on the Youghiogheny and Kiskiminitas watersheds; and the 1884 flood, caused by a winter thaw and moderate rains, furnished a greater total discharge in the Ohio River here than the notable inundation in the spring of 1913.

Standard building design allows for the weight of snow on roofs. Accepted practice protects electrical wires for operating motors, lights, etc., from short circuit, though where deep drifts are likely the wires must be sufficiently elevated to avoid grounding.

Unless melted by rain or temperature and then frozen, average snowfall will not hinder operation of exposed mechanisms, though it may affect accessibility to these.

DROUGHT PERIODS

The hydraulic engineer must measure intervals of deficient precipitation by records of occurrence and quantity, rather than by their effect on vegetation, especially as to the harvesting of crops which fail if requisite moisture is not absorbed at certain critical stages.

Reservoirs, streams and sub-surface waters, largely dependent on melted snow, will materially respond to deficiency of this deposit; storage basins relying on spring or autumn rains for replenishment become seriously depleted by unseasonable droughts, and high run-off from an intense storm falling on sun-baked soil results in a catchment exceeding the benefit to agriculture.

A succession of years of deficient precipitation exhibits the effects in reduced underground water storage. The late Dr. W. J. McGee stated:

> Normal streams, being derived chiefly from seepage, are maintained directly by the store of water accumulated in the ground as the residuum of rains of preceding seasons and decades, and only indirectly by current rainfall. In the humid part of this country the ground water within the first hundred feet from the surface has been estimated at some 25 per cent of the volume of subsoil and rock, equivalent to 6 or 7 years' rainfall, i.e., it may be conceived as a reservoir of water 25 feet deep, coinciding in area with the humid region.

Where ground waters are the direct source of supply a period of deficient precipitation will exhibit the effect, and in some areas levels of ground waters are due to rainfall conditions at a distant locality. With lowered ground water levels changes in the character of the water supply are to be sought for. Smaller subsoil basins also become depleted by successive years of subnormal precipitation, one illustration of this being given in the records of some Pennsylvania streams fed by limestone springs. In 1910, the third successive year of deficient rainfall, these reached lower stages than in 1908, which experienced the most severe drought of the three years. As a contrast, many other streams supplied more largely by direct runoff showed minimum records in 1908.

The deficiencies of precipitation follow no known laws of extent or occurrence. The drought condition of July and September 1881 covered most of the territory east of the Mississippi River. March 1910 was dry and unusually warm over most of the United States, and the year was generally dry, especially in a large area in 7 contiguous states. The lack of rainfall affected many large areas in 1894 and 1895, the first being intensified by the low rainfalls of 1893. Some of the regional deficiences for 1894 and 1895, respectively, were:

Ohio Valley and Tennessee	11	and 11	inches
Upper Mississippi	12	and 7.8	inches
East Gulf	9	and 8.6	inches
New England	8.1	and 5.3	inches

Drought conditions in Pennsylvania occurred in 1876, 1881, 1887, 1895, 1900, 1904, 1908, with 1909 and 1910 also with pronounced deficiency, and in 1914. The recent succession of years with subnormal precipitation in much of New England and part of New York State has been widely noted.

In the period October 1910 to July 1911 the Arkansas River at Little Rock, draining 148,241 square miles, gave record low water stages since 1879, for each month of the interval. The summer and autumn of 1870 and the winter following, at Baltimore, Maryland, were each lacking in precipitation, the total deficiency being 15.18 inches. From November 1910 to May 1911, 6 Weather Bureau stations in Georgia and the Carolinas had from one-third to one-half of the normal precipitation for the period. The lowest proportion was at Charleston, S. C., which received but 23.06 inches. Old records credit this city for the interval October 1757 to April 1758, with but 4.95 inches of rain.

The 1903 drought in Kansas, the most severe in 60 years, which afforded for 3 months a total average rainfall for the state of 37½ per cent of the average, was the fourth consecutive year of deficient precipitation for that region, and the same summer, especially the month of August, produced droughts in 5 neighboring states.

Atlanta, Georgia, records deficient intervals as given in Table 7.

TABLE 7

Some drought periods at Atlanta, Ga.

INTERVALS	DAYS DURATION	PRECIPITATION DURING DROUGHT	
		No. days	Total amount, inches
August 10–October 21, 1884.....	73	9	0.28
September 13–November 11, 1886...	60	7	0.42
September 14–November 9, 1891...	57	6	0.18
August 31–October 10, 1897.....	41	2	0.14
September 5–November 1, 1904.....	58	1	0.10

From July 1910 to June 1911 the quantity noted was but 43 per cent of the normal.

Prof. A. J. Henry some years ago made an exhaustive investigation of droughts, considering as such intervals of three weeks or more when the total precipitation was 30 per cent less than normal. From more than 1000 of such periods at 20 selected stations east of

the Rocky Mountains, he listed the averages of the precipitation in the two weeks preceding, and that during the drought, and the proportions of each to the normal. The range in values was as follows:

Number of droughts per year	22–46
Per cent of precipitation in previous two weeks to normal for the period	144–218
Average days duration of drought	29– 47
Per cent of precipitation in drought to normal in that period	17– 24

Of these he wrote:

> Drought periods are preceded, in the majority of cases, by a single heavy rain or by several days of light to moderate rains. . . . . This appears to be true of both the semiarid regions of the west and the more humid regions of the east and south. . . . The depth of rainfall in the two weeks preceding droughty periods—that is whether 200 or 400 per cent of the normal, does not appear to bear any relation to the length or intensity of the drought.

That subsequent data and studies have caused no modification in his deduction attests the soundness of his conclusions.

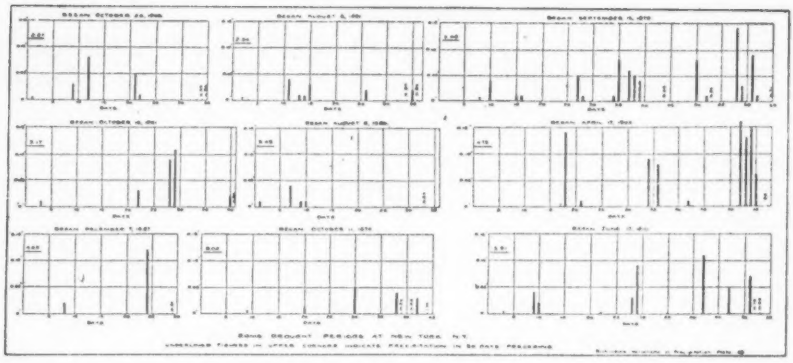
It is evident that some kind of a balance must exist, for deficiencies in precipitation can only occur when the causative conditions are reduced; likewise that the accumulated absorption of moisture by warm air is eventually subject to some condensation.

The meagre rainfall of Charleston, South Carolina, for the 6 months beginning November 1910, was succeeded by a 3 months interval, with 126 per cent of the normal precipitation. The excessive rains of September 1914, at Kansas City, Missouri, followed 2 droughts, from early April to mid-June, and again from early July to late August.

Mr. D. C. Reed's recent compilation of droughts in New York City lists the precipitation in the previous 30 days, and shows the subsequent rainfall records. Some of these are given in plate 29 and others in Table 8.

Similar data for droughts in Philadelphia, Pennsylvania, are offered on plate 30 and in Table 9.

Also beginning with July 23, 1895, 1.90 inches in 81 days; and in the 85 days subsequent to August 22, 1914, 2.85 inches. This last was followed by an unusual excess, the succeeding 72 days having a total of 16.06 inches of rain.

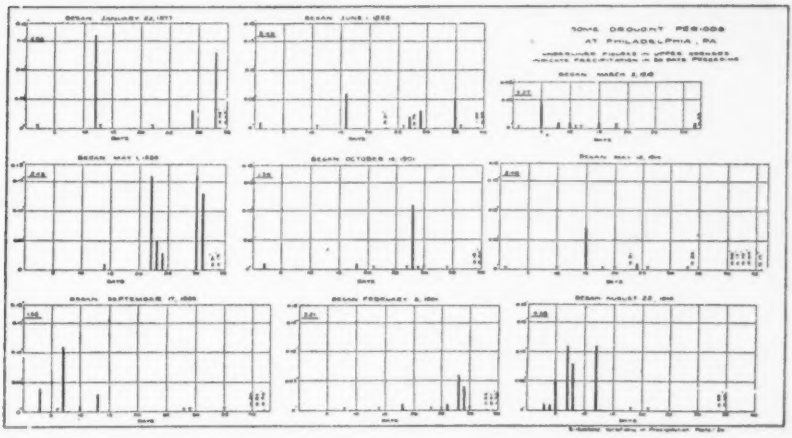


Boston, Massachusetts, subsequent to May 13, 1914, experienced 21 consecutive days of no measurable rain, then 0.10 inch in 1 day, and 10 successive dry days. This drought was preceded by 4.03

TABLE 8

Some drought periods at New York, N. Y.

BEGAN	PRECIPITATION IN PREVIOUS 30 DAYS	TOTAL PRECIPITATION IN		SUBSEQUENT PRECIPITATION IN		MAXIMUM CONSECUTIVE DAYS WITH LESS THAN 0.01
		Days	Inches	Days	Inches	
February 15, 1872	1.97	24	0	1	1.58	24
August 26, 1874	3.01	21	T	1	0.96	21
September 1, 1884	8.56	28	T	1	0.11	28
		31	0.15	1	0.28	
		41	0.32	1	0.11	
		51	0.43	1	0.80	
September 24, 1886	1.98	32	0.02	1	0.28	20
				2	2.99	
April 30, 1887	3.67	26	0.13	1	0.35	17
				3	0.86	
September 7, 1908	5.74	48	0.94	2	0.86	21
October 28, 1909	1.29	26	0.11	1	0.31	14
				3	1.35	
March 8, 1910	4.54	27	0.25	1	0.20	14
		40	0.51	1	0.72	
				3	1.74	
September 10, 1910	2.01	35	0.31	1	0.03	27
		40	0.34	1	3.04	
August 30, 1914	2.18	46	0.20	1	0.06	25
				2	1.70	



inches in 30 days, and followed by 1.20 inch in 6 of the following 16 days. The maximum continuous dry period was 25 days, beginning in late August 1874.

TABLE 9

Some droughts at Philadelphia, Pa.

BEGAN	PRECIPITATION IN PREVIOUS 30 DAYS	TOTAL PRECIPITATION IN		SUBSEQUENT PRECIPITATION IN		MAXIMUM CONSECUTIVE DAYS WITH LESS THAN 0.01
		Days	Inches	Days	Inches	
October 11, 1874	8.88	38	0.22	1	0.13	29
		40	0.35	3	1.13	
December 7, 1877	3.70	23	T	6	0.70	23
August 22, 1881	1.51	19	0.01	1	0.20	18
September 1, 1884	4.30	28	0.09	2	0.11	22
		31	0.20	2	0.26	
		51	0.58	1	0.44	
June 8, 1894	9.88	16	0.02	1	0.12	10
		22	0.16	1	0.14	
		39	0.41	2	0.17	
		57	1.05	2	0.97	
October 14, 1895	1.91	17	0	1	1.32	17
October 26, 1905	4.06	29	0.16	1	0.12	10
		33	0.28	2	1.33	
September 7, 1908	5.00	21	T	1	0.67	21
October 3, 1908	2.01	21	0.06	7	1.62	11
August 21, 1909	3.17	20	T	1	1.59	20
April 30, 1913	6.89	16	0.03	2	0.51	14

A record period of 75 consecutive days without measurable precipitation occurred at Portland, Oregon, June 25 to September 5, 1914.

Another classification of drought periods is illustrated by the accompanying table of periods of 35 or more consecutive days between March 1 and September 30, when less than 0.25 inch in the 24 hours was recorded at Philadelphia.

The plates and tables illustrate the variability in occurrence and quantity of precipitation during deficient intervals. Such data are given much attention in studies of water supply, as they indicate the deficient periods to be provided for and the evaporation conditions to be anticipated.

TABLE 10

YEAR	INTERVAL	NUMBER OF DAYS
1877	July 30–September 5	38
1884	August 30–October 21	53
1885	February 26–April 3	37
1893	July 18–August 23	37
1894	June 7–August 2	57
1896	July 31–September 4	36
1906	August 30–October 3	35
1914	May 6–June 14	40

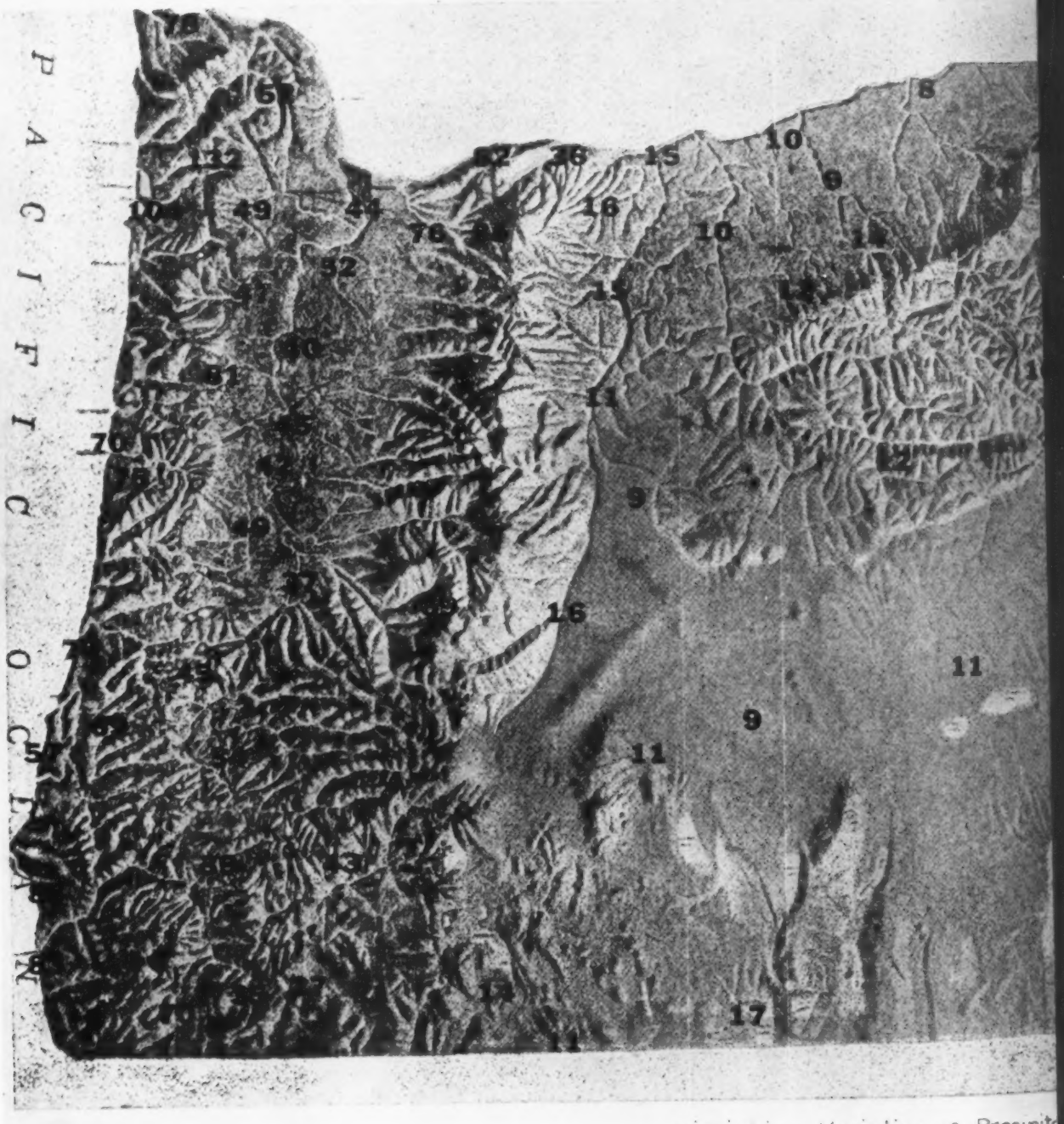
NOTE: When periods of 20 or more consecutive days were taken the maximum occurrence was in April.

VARIATIONS OF PRECIPITATION WITH ALTITUDES

The Pacific Coast is the most notable example in the United States of the largely increased precipitation on the mountains adjacent to the ocean when the general wind direction is offsea, and this is illustrated on plates 31 and 32, which show the average precipitation for a number of years in Oregon, and for California in 1914 and March, 1915, and how the eastern slope of these mountains receives a notably decreased rainfall. The western slope of the Wasatch Mountains in Utah, with its precipitation in excess of that for the balance of the state, is interesting because of the greater distance from the ocean.

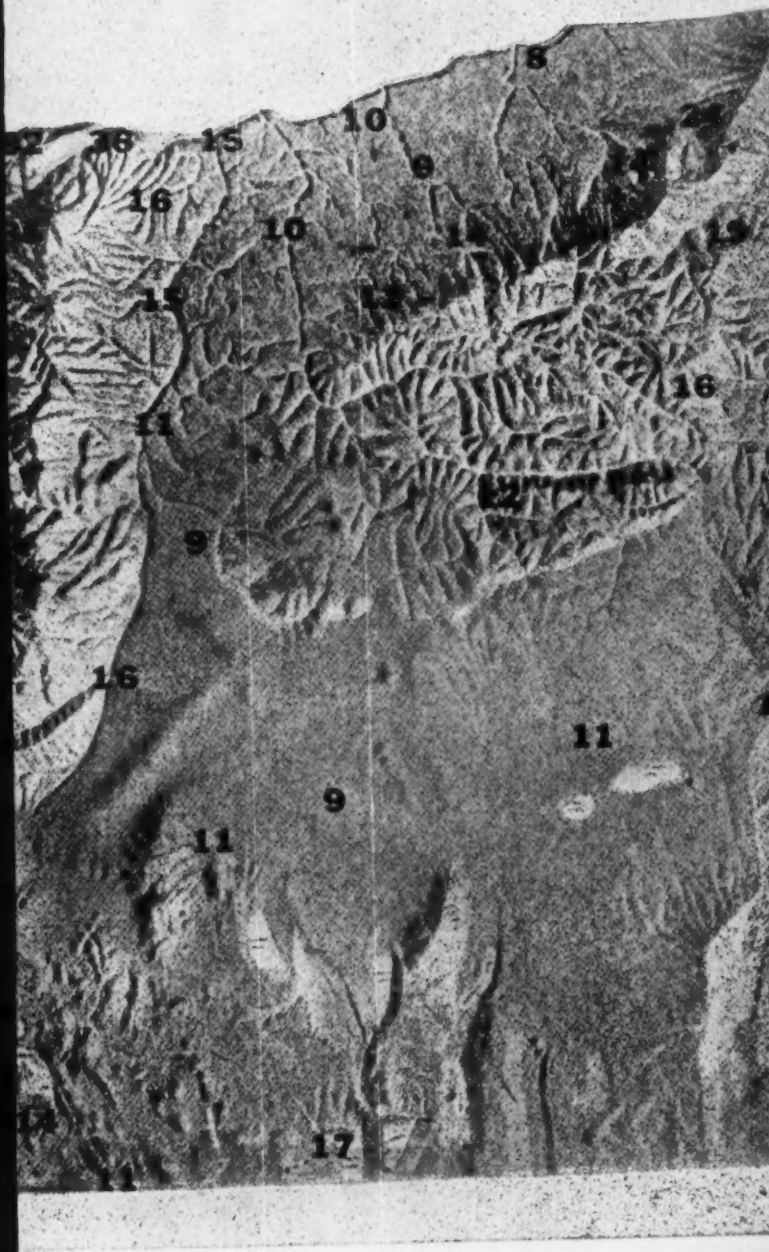
On the eastern coast Mount Washington stands as a notable instance, and the higher rainfall on the southern Alleghany Moun-

AVERAGE ANNUAL PRECIPITATION. OREGO



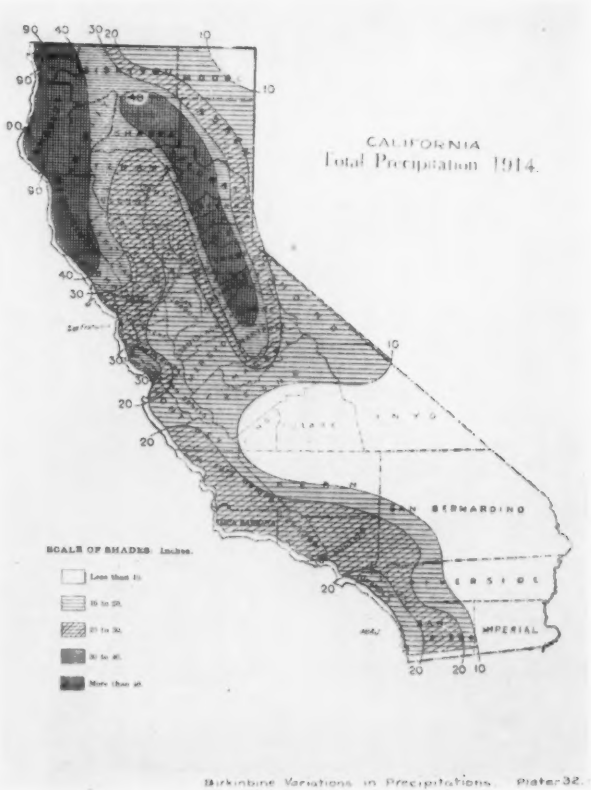
Birkinbine. Variation in Precipit

NUAL PRECIPITATION. OREGON.



Birkinbine. Variation in Precipitatio

pitation. Plate.–31.



Burkinbine Variations in Precipitations. Plate 32.

The influence of the diversified topography of California upon its precipitation is shown by the lines of equal rainfall in inches on the accompanying relief map.

tains, especially in the more southern portion, is another specific example. Mr. R. R. Briggs, in 1914, compiled a tabulation of July records for 18 years of rainfall, and altitudes covering 104 stations in Arizona, which is given below.

A number of records and charts showing increase of precipitation with mountain altitudes have been prepared for different sections, especially for the Pacific Region. Mr. Brook's diagrams of snowfall and altitude across New York, West Virginia and New England show the increase of snow fall with altitude as modified by exposure to moist winds.

Pennsylvania records (see plate 4) show greater total precipitation, but in fewer days, for the stations east of the Alleghenies than those

TABLE 11

Average for 18 years of July rainfall at different altitudes in Arizona

NO. OF STATIONS	ELEVATION	AVERAGE RAINFALL	AVERAGE NUMBER RAINY DAYS
	feet	*inches*	
8	Below 1000	0.33	1
16	1000 to 2000	0.63	5
11	2000 to 3000	2.72	10
16	3000 to 4000	2.79	10
20	4000 to 5000	3.95	14
16	5000 to 6000	4.05	12
10	6000 to 7000	5.01	17
5	7000 to 8000	5.70	21
2	8000 or above	7.12	29

on the western side, and that the region of greatest precipitation is not that of maximum altitude. Study of the rainfall conditions in Pennsylvania (see plate 4) and New York illustrate how the effect of other conditions breaks the harmony between altitude and precipitation. The proportion of measuring stations in the mountain regions of these states is less than for the more populous districts, but there are sufficient to illustrate the variations in snow and rain, which, while affected by topography, are modified in a pronounced manner by wind direction, proximity to water surfaces and by storm paths.

The former idea of a considerable variation in the rainfall between the earth's surface and a short distance above seems to have generally disappeared. Mr. John E. Codman, C.E., of Philadelphia,

made a number of experiments some years ago with receiving vessels at different positions on a 50 foot mast, and concluded that the variations were due to counter-currents caused by the pole.

The city of Philadelphia for some years maintained a gauge at the ground surface, and adjacent to it an automatic gauge placed 13 feet above the earth. It was found that during storms with high winds the catchment of the elevated gauge was diminished by the roof of a building. Omitting occasions when such conditions occurred, the variation in quantities received by each was but a few hundredths for monthly totals, and such minute discrepancies may be caused by method of measurement in gauges of different type. The total difference of these two gauges was in some years less than that between measurements in different portions of the city.

At Columbus, Ohio, the Weather Bureau and the State University each maintain rain gauges, the former on the roof of an office building, and the latter on the ground in a open space three miles distant. The average monthly records for 29 years showed a monthly variation of the University gauge, referred to the Weather Bureau gauge as standard, of from -0.34 inch to $+0.20$ inch, and the average annual totals were 35.64 inches for the Weather Bureau Station and 36.16 inches for the University station, a difference of $1\frac{1}{2}$ per cent. Such discrepancies are small when the distance between gauges is considered, for this region receives severe storms over small areas.

It is evident that ill-chosen exposure on a roof will result in improper records because of air currents being changed by cornices, skylights, etc., and the naturally greater wind velocities in high elevations will produce some reduction by driving the rain on the gauge at a greater angle. The effect of winds in varying snow depths is exemplified in mountain regions, and in the "blizzard" type of snow storms. But it is difficult to accept any theory of radical differences, due to a few hundred feet of elevation alone, for any suggestion of humid air near the ground being absorbed by a rain drop in passage must be met by the query of how long the lower stratum of air can supply such additional moisture.

PERIODIC VARIATIONS

Considerable attention has been called to the theory of periodic changes in climate and to cycles of rainfall. Geological investigations have shown the existence in the past of climatic conditions

very diverse from those now prevailing, many of which are visible in topographical features.

A notable investigation on the variation in climate is that of Prof. Eduard Brückner, based upon oscillations in water surface of the Caspian, Black and Baltic Seas which vary with the heights of the rivers feeding them, the vintage season in south France, Germany and Switzerland subsequent to 1400, records of ice on rivers after 1738, occurrence of severe winters since 800, advances and recessions of Alpine glaciers for 400 years, temperatures in Europe and New England, and precipitation records of Europe and midland North America. These plotted up to 1865 showed an expected harmony between temperature and rainfall, and from the curves Professor Brückner deducted an average period for cycles of 35 years, the maxima of rainfall in the past century occurring in 1815, 1850 and 1880, and minima in 1830 and 1860.

Dr. Julius Hann had called attention to the variation in inland seas as early as 1867, and R. Sieger discussed secular variation in lakes in different regions. Muschketoff, Rossikoff and Brückner reviewed a quarter century ago the desiccation of lakes in Eastern Turkestan, Northern Caucasus and Western Siberia. C. K. Gilbert, in his monograph on Lake Bonneville (now Great Salt Lake), concluded that this had experienced 5 extended periods of high and low level, which had crests of extreme magnitude, and that the last was the present stage of low and decreasing level, this was in 1890. Mr. L. H. Murdock in 1901 charted the water levels and precipitations at this lake, which indicated a harmony in the two curves, though his later records showed a more rapid diminution in water elevation than precipitation, explained by decreased catchment due to more extensive utilization of water by agricultural development. Mr. I. C. Russel's monograph on Lake Lahontan in Nevada deduced similar periods of level fluctuation.

Dr. Ellsworth Huntington has made exhaustive studies in portions of Asia and certain regions of the United States, Mexico and Guatemala. His work, "The Climatic Factor," presents much interesting data concerning the evidences of past climatic changes as typified by geology, archæology, history and botany.

Mr. E. E. Free, after a study of the Otero Basin in New Mexico, wrote,

> The whole history of Lake Otero and of the period since its disappearance is a record of great and continuous climate changes, with major fluctuations

indicated by the variations of the great ancient lake and its deposits. On these fluctuations are superposed many series of minor pulsations, the greater of which can be read in the triple record of changing topography in lake, dunes and arroyos.

Prof. E. A. Douglas and Dr. Huntington have made painstaking investigations into the thickness of annual rings of tree growth on specimens of yellow pine in Arizona and sequoia in California, covering periods of from 250 to 3150 years. Dr. Huntington corrected for age and longevity and used the data thus obtained as an index to past precipitation records. Huntington's resulting curve is reproduced by permission on plate 41, and gives a long continuous record of conditions at one region. The investigator has found a harmony between the growth of these trees and of the level of Owens Lake in California.

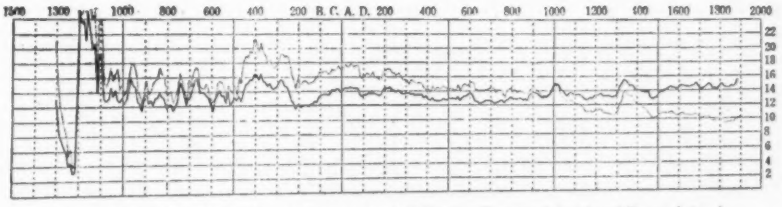


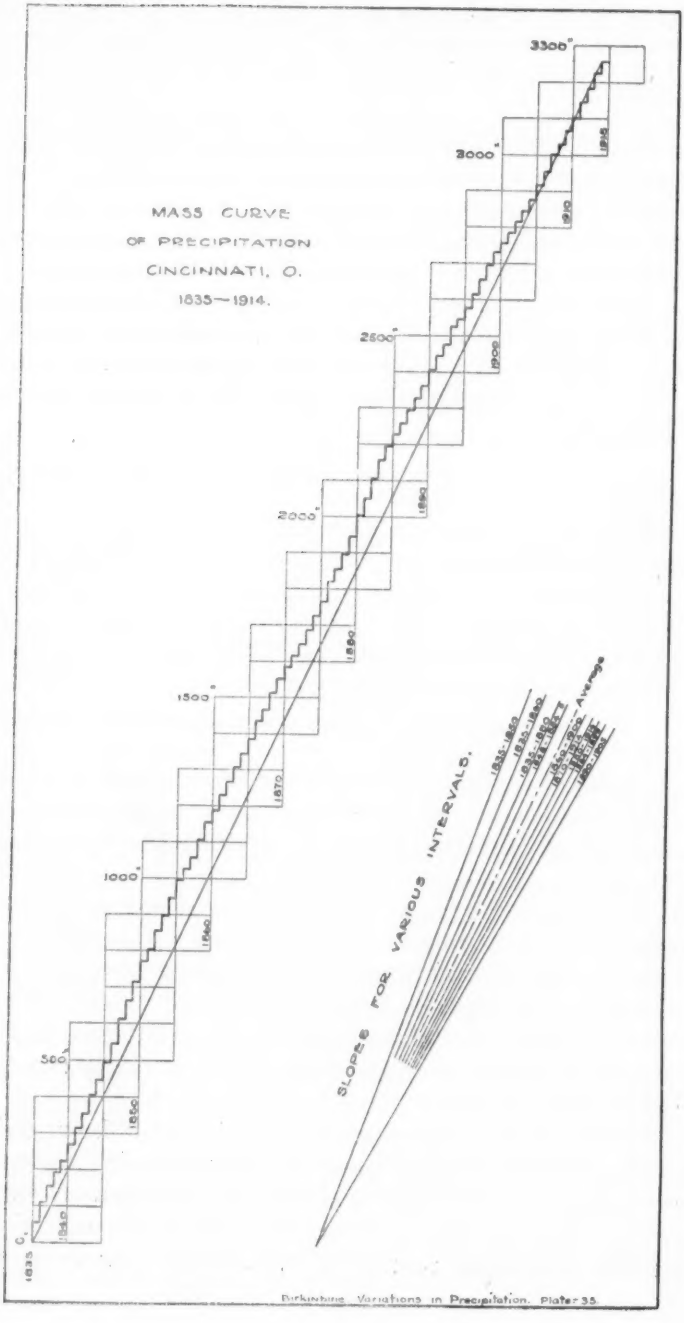
FIG. 33.—Curve of Growth of the *Sequoia washingtoniana* in California. Uncorrected (. . .) and Corrected (——). (See Table E, pp. 308-310.)

BIRKINBINE. VARIATIONS IN PRECIPITATION. PLATE 41.

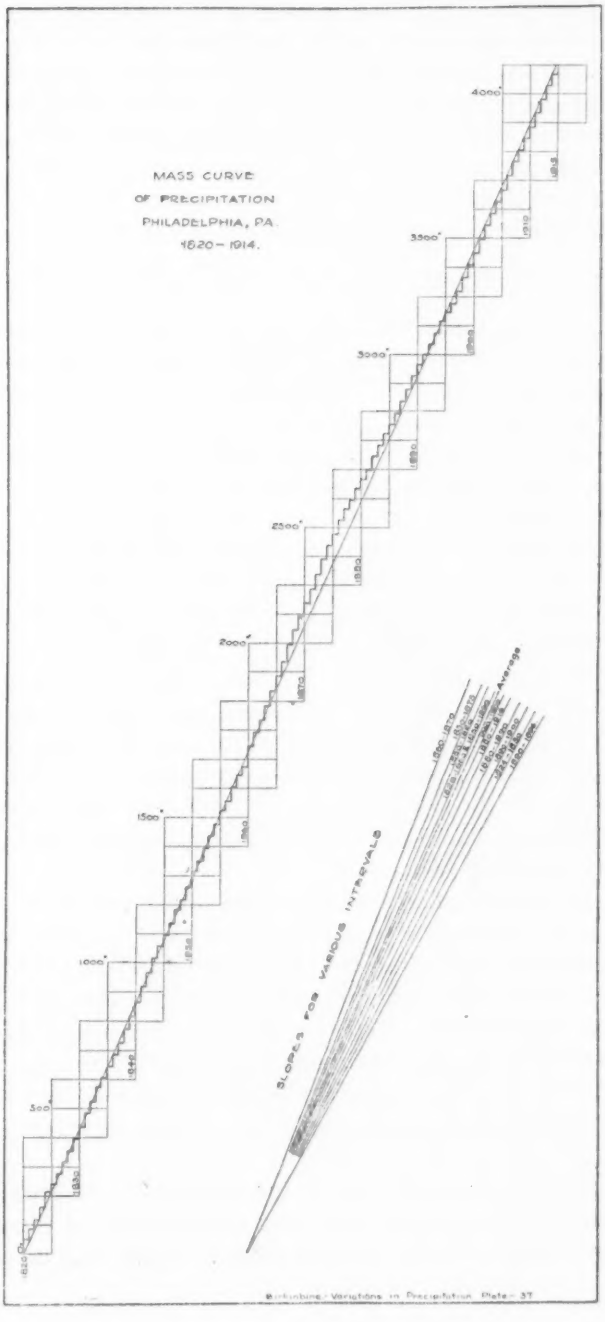
The growth of vegetation is affected by the material in which it roots and the occurrence of rainfall in the growing season, but such investigations offer another means of acquiring knowledge of past conditions.

Mr. W. M. Stewart's investigation of the annular rings of an oak at York, N. Y., with adjacent precipitation records at Rochester, covering 75 years, showed correspondence between growth and the quantity of rain in June and July, months included in the growing season of the oak. Huntington's investigations indicated that the precipitation in March, April and May were most closely related to the growth of the sequoia.

To illustrate the diversity of precipitation through different periods plates 35 and 37 have been prepared by plotting data in mass curves, above which are shown the slopes of increase for intervals of various durations. That the data used are mainly of one general region is because this offered most examples of long records. The mass curves



Birkinbine, Variations in Precipitation. Plate 35.



Bookstaber: Variations in Precipitation. Plate 37

indicate by inspection marked variations, the slopes of increase for various intervals are shown, while any others desired may be taken by a straight line between points, or the total for any period, and from it the average, may be read by differences in ordinates.

Some method of adjustment is demanded to modify the use of the calendar year and to distribute the extremes; various methods being progressive averages for intervals of different length, determined by simple arithmetical means or by giving additional weight to the middle years of the period. Blanford's formula, $\frac{a+4b+6c+e}{16} = c'$, for 5 year intervals, has continued in favor among meteorologists.

The above mentioned studies, actual yearly totals, smoothed averages by various methods, and the charts on plate 38 show cycles irregular in periods and intensity.

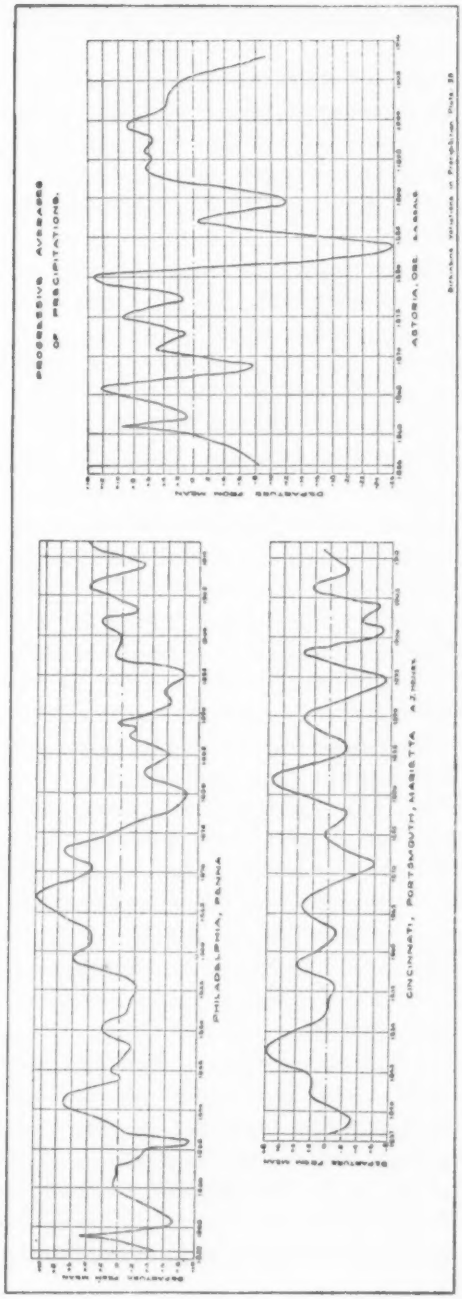
The curve for the Central Ohio region is according to Prof. A. J. Henry, and that of Astoria, Oregon, was prepared by Mr. E. A. Beals, who also evolved a similar curve for The Dalles, Oregon., which was more symmetrical than that for Astoria, and displayed a marked reduction in cyclic period for the later years. To include another region a curve for Philadelphia, Pennsylvania, which extends over a longer interval, has been computed and shown.

Professor Henry had, nearly 20 years ago, shown progressive averages of precipitation for south-eastern New England, the Ohio Valley and middle Mississippi Valley, which were later extended by Prof. D. W. Mead, who also showed similar curves for Wisconsin, San Joaquin Valley, California, and Charleston, South Carolina, and others have computed and plotted curves for specific localities and by various methods.

Regional data are preferable, where conditions permit for general studies, as the irregularities due to severe rains recording heavily at one gauge and passing beyond another are thus compensated for.

When a number of curves, smoothed by the same method, are plotted to uniform scale, there will be some instances of harmony shown; however, any general agreement is not to be expected, as the variations in precipitations are local, not general, and are due to various causes that are distinctly non-uniform in extent of area or time.

Local conditions are subjected to too many causes to permit their adherence to a general rule; also, any modifications of pressure at one place would naturally produce converse conditions at another


PROGRESSIVE AVERAGES
OF PRECIPITATIONS.
ASTORIA, ORE. AVERAGE
PHILADELPHIA, PENNA
CINCINNATI, PORTSMOUTH, MARIETTA AVERAGE.

locality, so that abnormal features at one point mean subnormal at another.

The northwestern portion of the country exhibits a peculiar tendency to 3 year intervals between high years and between low years, as shown by the records of Portland and Roseburg, Oregon, and Spokane and Seattle, Washington, whose individual records show a variation in magnitude between both high and low periods for different occasions.

The San Francisco records have been interpreted as subject to the full cycle periods, approximating 12 years, and cycles of different extent have been suspected at other localities.

The sunspots, with their 11 year period, have been frequently utilized in search for a harmony with climatic and meteorological conditions, on the basis of less solar radiation, and hence less precipitation with increase of sunspots. Professor Humphreys mentions the general inverse relation between sunspots and the average temperature of the earth as a whole, and the modification due to the quantity of volcanic dust in the upper atmosphere.

Prof. F. H. Bigelow found that temperature curves varied directly with sunspot curves on the Pacific Coast, inversely in the West Gulf States, and were indifferent to them in northern Arizona. Of this subject he wrote: "The numerous studies during the past 50 years into the apparent synchronism between the solar variations of energy and the terrestrial effects, as shown in the magnetic field and the meteorological elements, have been on the whole unsatisfactory, if not disappointing. Just enough simultaneous variation has been detected in the atmosphere of the sun and the earth to fascinate the attentive student. * * * Discussions of the spots are being replaced by others upon the solar prominences and faculae, which respond much more exactly to the working of the sun's internal circulation. * * * It is perfectly evident that if secular variations of any kind, such as the annual changes in terrestrial pressure, temperature or the magnetic field, are to be attributed to solar action, the original observations must be finally reduced to a homogeneous system. The local peculiarities of each station must be carefully eliminated, and the data of numerous stations must be concentrated before anything like quantitative cosmical residuals can be obtained. * * * The skeptical attitude of conservative students, who declare that the many indecisive results already obtained mean that there is no true and causal solar-terrestrial syn-

chronism, is of course quite fallacious until it has been demonstrated by the use of first class homogeneous data that the suspected physical connection is imaginary."

Dr. Hann wrote: "The results of very numerous and complex investigations of the connection of the sunspot period with variations in the meteorological elements have not wholly corresponded to expectations. * * * There can be no thought of the prediction of the weather on the ground of the sunspot cycle."[3]

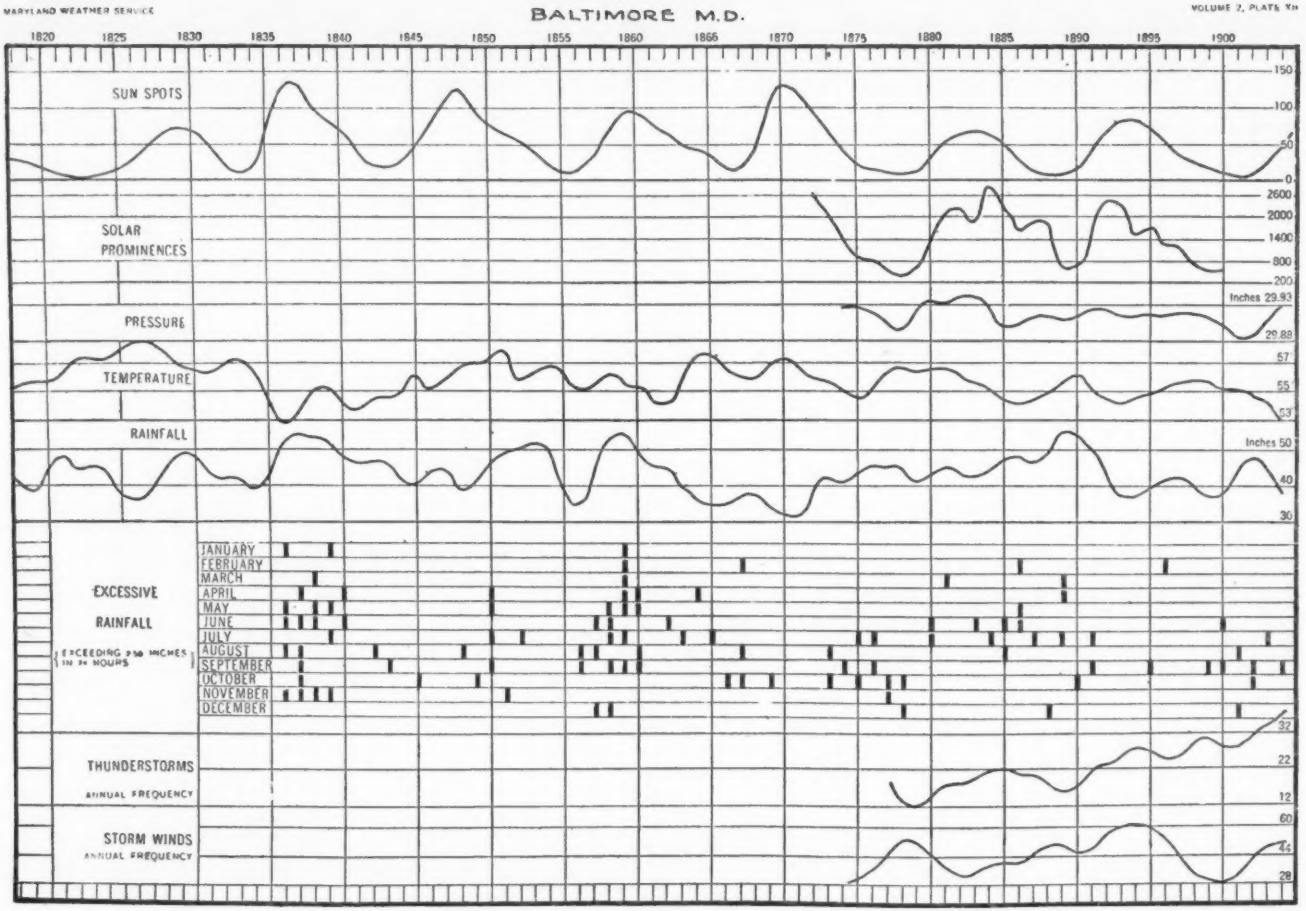
Professor Fassig plotted data up to 1904, using Wolf's data of sunspots and solar prominences, and also the Baltimore annual data of pressure, temperature, total rainfalls, number of thunderstorms, and frequency of storm winds exceeding 25 miles per hour, the curves of Baltimore data being smoothed by the formula $\frac{a+2b+c}{4} = b'$, a, b, and c being actual values for 3 successive years. The rainfalls greater than $2\frac{1}{2}$ inches in 24 hours were also plotted, and his chart, reproduced by permission, illustrates the variation shown in the different curves. (See plate 39.)

Assumptions that other agencies in the solar system appreciably affect the quantity of moisture received have fallen to the rear as actual meteorological knowledge has advanced. To illustrate the minor effects of such, Professor Humphreys has calculated that the planets by gravitational action could produce perturbations in the earth's orbit which occasionally, under the most favorable circumstances, could alter the actual surface temperature by as much as 0.02°F., and that an equal difference may be brought about by the varying distance of the earth from the sun as the earth and moon rotate about their common center of gravity.

Professor Fassig, referring to the records of maximum 24 hours precipitation at Baltimore, Maryland, for each year from 1871 to 1903 said: "The tendency to a periodic fluctuation embracing a group of years is more marked than in those representing the total seasonal or annual fall." This is an interesting case, but is to be taken as a single example.

Prof. A. J. Henry wrote in 1913: "Since systematic observations began there has not been a single year when precipitation was above normal in all parts of the country, and but one year when it was deficient in all parts of the country in one and the same year. The

[3] This was written before the researches and studies of Arctowski.



SUNSPOTS, SOLAR PROMINENCES AND WEATHER CONDITIONS. COURTESY O.L.FASSIG.

(Smoothed annual values for weather conditions, excepting, excessive rainfalls, which are observed values.)

Plate-39

Birkinbine. Variations in Precipitation

abnormalities for the smaller climatic units, since the units are of unequal size, do not readily lend themselves to a combination, but considered separately, they indicate the interesting fact that in the Rocky Mountain Region, from Montana southward to the Mexican border, the number of years with precipitation above the normal is very nearly equal to the number of years with precipitation below the normal. East of the Mississippi, and in the Gulf and South Atlantic States especially, the number of years with diminished precipitation is in a very decided majority. Further, it would seem that years of fat or lean precipitation do not follow any recognizable sequence, and that the most probable value for any year is not the arithmetical mean or normal for the latitude, but a value near but slightly below the mean. On the other hand years of excessive rainfall do not occur with the same frequency as years of light rainfall; heavy rains seem to be due to extraordinary and probably worldwide temperature and pressure relations, which appear to be the cause of unusual storm movement with its attendant precipitation. Thus, in 1912, the prevalence of an unusually large number of south-west storms and the rains attending them produced the great flood in the lower Mississippi Valley of 1912. The calendar year is much too great a unit for comparative purposes. Unfortunately the labor of assembling the data in a more convenient form is so great as to be prohibitive."

Doctor Hann, in discussing the inconstant distribution of the climatic elements, said: "There are at least certain fluctuations about a common mean, even if no progressive changes in a given direction take place."

Many investigators and meteorologists discredit any supposed climatic changes in a century or two, although the disposition to cyclicism is recognized as well as the irregularities.

Artificial conditions, produced by man, may be charged with some differences in visible effects of precipitation. The increased flood heights, due to constriction and obstruction of stream channels, has at some localities reached a stage requiring preventive legislation or compensating improvements. The extended use and too frequent waste of ground waters has drawn heavily on many subsurface basins, and storage dams for their different uses, artificially change the natural stream discharge and often cut off an underchannel and subsoil flow. Slight changes in character and amount of precipitation are sometimes claimed to occur with agricultural

Plate-39
Birkinbine. Variations in Precipitation
(Deviations annual values for weather conditions, excepting excessive rainfalls, which are observed values.)

development and deforestation, while the runoff is materially affected by such factors.

But that an actual and appreciable change in climate, temperature and precipitation conditions is now in effect has not been determined to the satisfaction of those who have made exhaustive studies.

CONCLUSIONS

The economic considerations of engineering are recognized when these do not conflict with safety. The construction and operation of water works are more than a financial investment or a convenience; for not only the comfort and development of a community, but also its health and life are affected. Consequently, protective and preventive measures against interruption or destruction must be made with a wider margin than for such engineering works as are merely business improvements.

That the many variations of precipitation which furnishes the supply have been properly considered and met by engineers is attested by the large number of plants in successful operation. That each instance is a special problem is one of the pleasing features of engineering work, and it is hoped that this paper will encourage the distribution of data concerning unusual conditions that are of interest and value to the profession.

DISCUSSION

Mr. William W. Brush: Mr. Birkinbine has collected such a vast amount of material that it is impossible to discuss his paper as a whole. The speaker had an opportunity to read the greater part of the paper, and thought it might be of interest to point out the variation in the amount of water available as a result of precipitation in a watershed from which the supply was drawn from the subsurface water levels, and in a watershed where it was drawn from surface runoff.

The distance between the Croton watershed and the Long Island watershed is only about 45 miles. The rainfall conditions are usually similar, although, as has been shown, the Croton precipitation is greater than the Long Island. The runoff conditions are entirely different, the Long Island watershed being an extremely pervious soil, mainly sands and gravels, with some clay at varying

depths. The greater part of the rainfall reaches the underground water table, only a small portion appearing in the streams which form in slight depressions on the south side of the Island, where the surface of the ground dips below the water table. The Croton watershed is composed of a typical mixture of various soils usually found in a hilly country, there being no well defined underground water table. The rainfall usually has but a short distance to travel before it reaches a stream.

At the end of the drought period extending from July 1910 to July 1911 there was a very heavy precipitation, especially in the month of August, on the two watersheds. This precipitation on the Brooklyn watershed amounted to 10 inches; on the Croton watershed it was a little over 8 inches. It was followed in September with precipitation of 2 inches and in October about 6 inches.

The total underground flow on the Long Island watershed has never been determined; but the best data available to determine the underground flow at any particular part of the watershed are from the yield of an infiltration gallery, which, at Wantagh, Long Island, is made up of about 12,000 feet of pipe laid 5 to 14 feet below the normal water table at right angles to the direction of flow. This gallery, when operated, takes practically the entire flow of the underground water table above the clay bed, which is approximately 100 feet below the surface. In the summer of 1911 the Wantagh gallery showed a reaction of from 15 to 20 per cent in yield from July to October, the low yield being in the month of October, in spite of the high rainfall period for the months of August, September and October. On the Croton watershed, with a surface runoff, the runoff in July amounted to 25,000,000 gallons per day, whereas, by October it had increased to over 600,000,000 gallons per day, or about 2500 per cent. With the surface supply of Long Island the yield may not increase for several months after the drought has been broken by copious rainfall, due to the rainfall on the greater part of the watershed not reaching the collecting works until months have elapsed. On a surface watershed like the Croton there is a very rapid augmentation in flow from a heavy rainfall, following a prolonged drought, the water only taking a few hours to reach the various streams, and the soil soon becoming sufficiently moistened to rapidly give up additional rainfall.

Mr. Andrew J. Provost, Jr.: Too much credit can hardly be given to the painstaking care and excessive labor employed by the

author in the presentation of the data which form the framework of this paper. It is unquestionably an important contribution to hydraulic engineering.

Although the author disclaims a purpose for his paper outside of an academic discussion of variations in precipitation, the data which he presents are worthy of further consideration in the manner and extent to which they may affect engineering design.

Water is, of course, the most important to man of the national resources, and the manner in which it is supplied for his uses is equally important. Nature is so capricious in this respect that man's ingenuity has been constantly taxed not only to conserve by regulation so that his needs may be at all times supplied, but also to safeguard his life and property from destructive oversupply. Drought and flood have probably, since the beginning, been as destructive to the human race as war and pestilence.

It is only during the past one hundred years or so in this country that records of rainfall have been observed or preserved, and there are only a few instances that cover more than a few decades. Most of these records, except very recently, furnish no data except the daily precipitation or the total for a storm. Measurements of intense rainfalls for short periods have bearing upon many important engineering designs, and it is to be regretted that the information available is so relatively meagre. Since the recent general use of automatic registering rain gauges a large amount of valuable data has been collected by various institutions and municipalities, and it is highly important that these results be made available to engineers.

The speaker has contributed, at the request of the author, and in amplification of his paper, a few tables and diagrams, to which he desires to add a very brief discussion of the uses of this kind of data in engineering design.

Table 1 indicates in a general way some of the more extended series of rainfall observations which have been preserved. These results are tabulated as average monthly precipitations over the entire periods of observation. Such records are of great value in the design of water works collecting basins and for determining the areas of watersheds required for a given supply. Records of this nature should be supplemented by diagrams similar to plates 5 and 6 of the author's paper. These show the maximum, average and minimum precipitation at various places. The following diagram com-

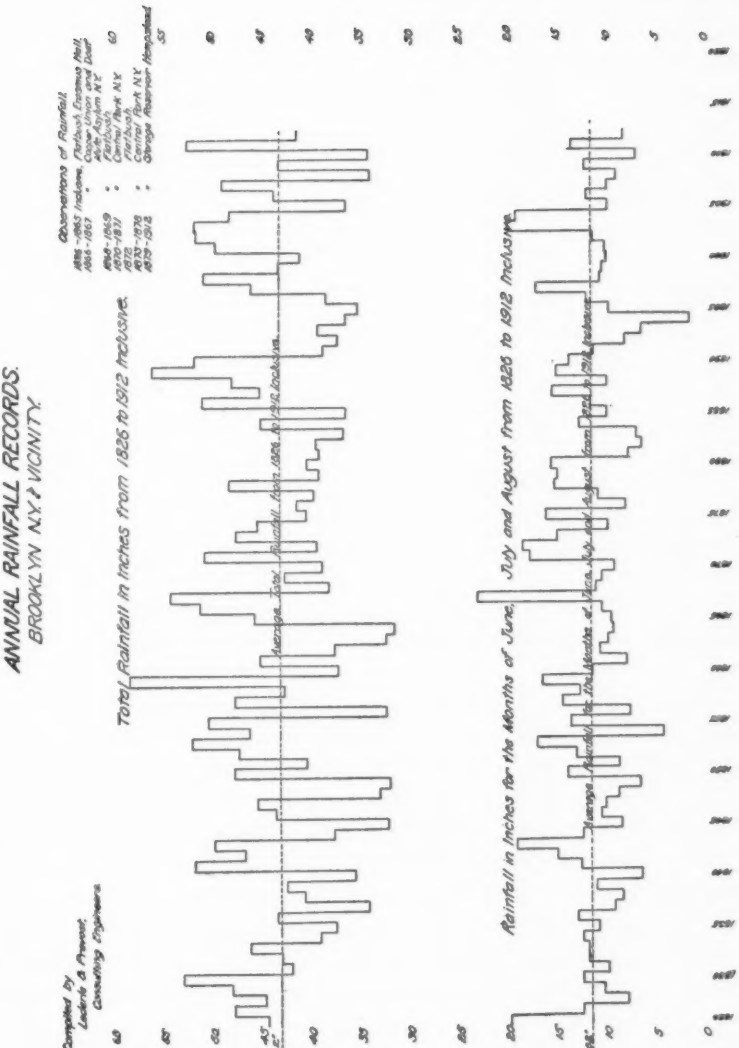

ANNUAL RAINFALL RECORDS.
BROOKLYN N.Y. & VICINITY.
Compiled by
Ludlow & Peckwell
Consulting Engineers
Observations of Rainfall
1826 - 1863 Inclusive, Flatbush Fluming Mill
1863 - 1867 " Corner Flatbush and Duryea
1868 - 1869 " Flatbush
1870 - 1871 " Central Park N.Y.
1872 - 1876 " Flatbush
1877 - 1878 " Central Park N.Y.
1879 - 1912 " Ridge Reservoir Hempstead
Total Rainfall in Inches from 1826 to 1912 Inclusive.
Average Rainfall from 1826 to 1912 Inclusive.
Rainfall in Inches for the Months of June, July and August from 1826 to 1912 Inclusive.
Average Rainfall for the Months of June, July and August from 1826 to 1912 Inclusive.

TABLE 1

Rainfall observations, various localities, extending over long periods. Average monthly precipitation, inches. Compiled by Lederle and Provost, Consulting Engineers

LOCATION	GAUGE ELEVATION	PERIOD	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
	feet														
New York City, Central Park....	97	1836–1913	3.40	3.48	3.76	3.56	3.89	3.73	4.12	4.61	3.68	3.85	3.54	3.67	45.29
Croton Water Shed, Various Gauges.....	200–600	1868–1909	4.15	4.11	4.25	3.49	3.86	3.57	4.71	4.94	4.24	3.99	3.65	3.96	48.92
Rochester, N. Y...		1872–1914	3.08	2.07	2.98	2.47	2.92	2.90	3.12	2.96	2.38	2.78	2.57	2.79	33.69
Long Island, N. Y., Various Gauges.....	30–50	1826–1902	3.29	3.21	3.52	3.35	3.64	3.35	3.99	4.12	3.40	3.62	3.69	3.38	42.56
Boston, Mass., Roxbury.....		1818–1914	3.70	3.49	4.10	3.81	3.56	3.10	3.47	4.01	3.37	3.62	4.06	3.74	44.10
Cambridge, Mass. Harvard College	75	1841–1913	3.97	3.55	3.97	3.62	3.41	3.13	3.34	4.23	3.54	3.55	3.99	3.56	43.86
New Bedford, Mass.....	100	1814–1913	4.01	3.88	4.34	3.95	3.96	3.07	3.23	4.17	3.54	3.94	4.24	4.15	46.47
Lowell, Mass.....	80	1826–1913	3.18	3.12	3.56	3.48	3.49	3.28	3.53	4.24	3.37	3.59	3.72	3.36	41.92
Waltham, Mass....	30	1825–1913	3.34	2.90	3.69	3.76	3.55	3.15	3.63	4.24	3.48	3.74	3.98	3.28	42.74
Providence, R. I...	163	1832–1913	4.07	3.85	4.19	3.77	3.64	3.19	3.26	4.03	3.35	3.67	3.98	4.01	45.01
Middletown, Conn.....	125	1858–1913	4.12	4.12	4.66	3.54	3.76	3.37	4.04	4.67	3.64	4.19	3.97	3.97	48.05
New Haven, Conn.	107	1804–1829 1864–1913	3.78	3.98	4.11	3.51	3.88	3.07	4.32	4.57	3.64	3.86	3.61	3.64	45.97
Burlington, Vt....	404	1828–1913	1.85	1.64	2.03	2.01	3.08	3.40	3.96	3.48	3.59	3.25	2.54	1.93	32.76
Hanover, N. H., Dartmouth College.....	603	1835–1913	2.67	2.72	3.21	2.50	3.19	2.89	3.69	4.02	3.56	2.88	2.71	2.97	37.01
St. Paul, Minn....		1837–1912	0.94	0.86	1.38	2.29	3.37	4.01	3.48	3.37	3.30	2.06	1.35	0.99	27.41
Albany, N. Y.....	97	1826–1913	2.59	2.44	2.75	2.64	3.50	3.95	4.04	3.77	3.33	3.41	2.93	2.63	37.98

piled by the speaker is for the same purpose. Records of this kind are most illuminating when reduced to diagrammatic form. The proportional extremes of annual precipitation in various places, as shown by the author in table 1, may be amplified by showing the percentage of maximum and minimum precipitation to the mean over extended period, as follows:

LOCATION	PERIOD	PER CENT OF MEAN	
		Maximum	Minimum
	years		
Boston, Mass	96	153	62
Detroit, Mich	43	149	66
Little Rock, Ark	34	154	68
New Orleans, La	78	153	55
Omaha, Neb	43	165	52
Richmond, Va	42	173	66
Rochester, N. Y	43	148	60
St. Louis, Mo	77	172	59
St. Paul, Minn	77	182	37
Brooklyn, N. Y	87	135	73

The Brooklyn record also shows that for three successive years during the period of 87 years, the minimum rain fall was only 78 per cent of the mean for the entire period.

For special purposes, such as spillway design, it is of greatest importance that accurate information exist regarding the maximum rates of precipitation, so that full provision may be made for disposing of surplus water with safety to the structures. For small watersheds with steep slopes and generally impervious surfaces it is necessary to provide spillway capacity for substantially all the rainfall from a short intense storm. Data of this character are also of greatest importance for the proper design of storm water sewers and culverts. Some records of intense rainfall in addition to those mentioned by the author are shown in table 2.

Data of this character were not available prior to about twenty-five years ago, and to this fact is due, in a great measure, the large aggregate damages to property which have resulted from inadequate structures.

An interesting fact alluded to by the author is the effect of intense precipitation upon the physical and sanitary character of the

TABLE 2

Records of intense rainfall. Total precipitation and rate in inches per hour during various periods. Lederle and Provost, Consulting Engineers

LOCATION	DATE	PERIOD IN MINUTES																		TOTAL IN 1 DAY
		5		10		15		20		30		40		50		60		120		
		Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	Total	Rate	
New York City:																				
Manhattan	July 10, 1915	0.7	8.9	1.3	7.6	1.6	6.5			2.1	4.2					2.3	2.3	2.6	1.3	2.74
Manhattan	July 28, 1913	0.5	6.1	1.0	5.8	1.2	4.8			1.5	3.0					2.7	2.7	3.1	1.6	3.11
Manhattan	September 5, 1913	0.6	7.2	1.2	6.9	1.6	6.4			2.6	5.2					3.3	3.3	3.7	1.9	4.14
Staten Island	October 1, 1913		6.0		5.6		5.2		5.1					3.8	4.6		4.4	6.2	3.1	7.54
Brooklyn	June 10, 1911			0.5	3.1			0.6	1.7	0.6	1.2									
Brooklyn	1907–1911				2.6				2.3		1.7		1.5		1.2		1.3		0.8	5.58
Erie, Pa	August 3, 1913	0.4	4.7	0.7	3.5	0.9	3.5			1.4	2.8					1.5	1.5	2.8	1.4	
Columbus, O	1897–1914	0.6	6.8	0.9	6.0	1.3	5.1	1.5	4.6	1.9	3.8	2.0	3.5	2.6	3.1	2.7	2.7		1.1	
Cincinnati, O	July 7, 1915	0.5	6.5	0.7	4.2															
St. Louis, Mo	July 14, 1912															3.0	3.0		0.9	10.2
	August 19, 1915																			
Kansas City, Mo	Various		6.5		4.5		4.0		3.6		3.3		3.0				2.4			7.0
Galveston, Tex	1898–1913				6.0	1.0	4.0		5.5		5.0		5.0		5.5		5.0	6.3	3.2	14.4
New Orleans, La	September 29, 1915	0.3	3.6	0.6	3.6	0.7	2.8			1.1	2.2					1.7	1.7	2.5	1.3	
St. Petersburg, Fla	August 2, 1915																			15.5

runoff, and the complications which are added to the treatment of the runoff at such times for the removal of physical and sanitary impurities. An instance of this kind is Esopus Creek, New York, which has a drainage area of abut 240 square miles, an average discharge of about 550 second feet, and an average summer flow, July and August, of about 90 second feet. The shed is in general sparsely populated, with the dwellings for the most part near the principal streams. In summer there is a large vacation population. Most of the buildings are provided with privies. The average characteristics of the main stream include:

Turbidity	about 7 parts per million
Color	about 6 parts per million
Chlorine	about 2 parts per million
Bacteria at 20°C	about 1,000 to 5,000 per cc. in summer
Bacteria at 40°C	about 100 to 1,000 per cc. in summer
B. Coli	about 10 to 100 per cc. in summer

These general characteristics obtained in June and July, 1914. On August 11 and 12, 1914, considerable precipitation occurred on this shed after about two weeks drought. Samples of stream water collected August 12 showed:

Turbidity	500 to 600 parts per million
Color	25 to 30 parts per million
Chlorine	4 to 6 parts per million
Bacteria at 20°C	about 50,000 to 230,000 per cc.
Bacteria at 40°C	about 20,000 to 60,000 per cc.
B. Coli	about 1,000 to 10,000 per cc.

These comparative analyses indicate clearly the pronounced effect of rapid runoff, under certain conditions, in temporarily changing the sanitary character of a stream.

Another important phenomenon of rainfall, and one which is not specially emphasized by the author, is the proportional rates and quantities, extending over considerable periods. A study of the records of the New York City Meteorological Observatory, over a period of forty-five years, shows that the greater part of the total annual precipitation occurs at the higher rates and during a relatively small portion of the total storm period. In other words, the greater part of the aggregate storm period is confined to light

rains which contribute much less than half of the total volume of the annual precipitation. This is illustrated in tables 3, 4 and 5 which cover a period of three years. These tables are based on the total amount of measured rainfall during each hour when precipita-

TABLE 3

Rainfall phenomena, New York City, proportional distribution. Proportion of aggregate storm period 1911 to 1913 inclusive, when certain rates of precipitation were exceeded. Lederle and Provost, Consulting Engineers. July, 1914.

YEAR	PER CENT OF STORM PERIOD WHEN RATES IN INCHES PER HOUR EXCEEDED				
	Trace	0.03 inch	0.1 inch	0.2 inch	0.3 inch
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
1911.....	100	59.10	15.10	4.85	2.50
1912.....	100	31.50	14.00	5.21	2.60
1913.....	100	64.40	15.80	7.06	3.93
Average...	100	51.50	15.20	5.72	3.00

TABLE 4

Proportion of annual precipitation 1911 to 1913 inclusive, falling at rates exceeding above rates

YEAR	PER CENT OF ANNUAL PRECIPITATION AT RATES EXCEEDING				
	Trace	0.03 inch	0.1 inch	0.2 inch	0.3 inch
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
1911.....	100	88.60	55.80	30.80	21.90
1912.....	100	80.80	62.60	37.90	24.20
1913.....	100	91.40	70.70	51.60	40.00
Average...	100	87.40	63.00	40.80	28.70

TABLE 5

YEAR	PROPORTION OF YEAR WHEN PRECIPITATION EXCEEDED RATES OF				
	Trace	0.03 inch	0.1 inch	0.2 inch	0.3 inch
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
1911.....	9.40	5.60	1.50	0.46	0.24
1912.....	9.80	3.10	1.40	0.51	0.25
1913.....	9.90	6.40	1.50	0.70	0.39
Average...	9.70	5.00	1.47	0.56	0.29

tion occurred, and do not include more intense rates for a period less than one hour, the data for which are not available. The tabular results show that for the years cited only 15 per cent of the storm period exceeded an hourly rate of 0.1 of an inch, and that during this brief period 63 per cent of the total annual rainfall was precipitated. If, instead of expressing these periods in percentage of storm period, as in table 4, we convert them into parts of the entire year, the results appear as in table 5, which shows by comparison that 63 per cent of the average annual precipitation for these three years (50.74 inches), amounting to 32 inches, was confined to an aggregate period of about five and one-half days (131 hours), and that over 40 per cent (20.7 inches) fell during periods aggregating about two days (49 hours).

This phenomenon, while interesting in many ways to water works engineers, has its most complete application perhaps to designs involving diversion of storm water from combined sewers connected to sewage treatment works. In the absence of data of this kind it has been the practice in the past for boards exercising governmental control in the design of sewerage systems, to insist upon the treatment of a much greater amount of storm water than appears upon close examination to be warranted in some cases. As an example it may be suggested that where the discharge of sewage is to be made into a large tidal estuary or other stream not used for potable purposes, the general sanitary character of such stream would not be ordinarily affected by the discharge of a portion of the sewage diluted with a relatively large amount of rainwater, during 5 per cent of the time, or about one and one-half days per month. This result could ordinarily be obtained in this locality by providing for the treatment of all surface water resulting from rainfall rates less than 0.03 of an inch per hour, and without, as a rule, materially increasing the cost of the treatment works to be provided.

In conclusion it may be said that most of the data relating to variations in precipitation and other rainfall phenomena now available in useful form have been compiled and arranged by engineers who could ill afford to spend the time required on this exhaustive research. It seems important that engineers should clearly designate the nature of the meteorological information which is required for their work in order that the observed results may be compiled and published in most useful form.

Credit should be given to Mr. Goodnough, Chief Engineer, Massa-

chusetts State Board of Health, for his recent valuable contributions with respect to extended rainfall records in New England.

MR. FRANCIS F. LONGLEY: Mr. Birkinbine presented one very striking diagram of the excessive runoff of the Ohio watershed in 1913, and made a comment in connection with it that it was the greatest rainfall that had taken place there. By that he no doubt meant that it was the greatest rainfall there of which there was any record. It is undoubtedly true that a great many people lose sight of the fact that the largest or smallest rainfall shown in the record of a station is probably not the largest or smallest that has ever occurred, or might ever occur, at that station. In other words, the longer the time you take for consideration of a record, the greater the maximum and the smaller the minimum is likely to be.

Our office has in the last year or so been studying the matter of variation of rainfall on the basis of probabilities, and it leads to some rather interesting possibilities in the way of predicting what the maximum or minimum rainfall may be. It does not enable one to say what the rainfall will be next year or the year after, but it does enable one to say with some degree of confidence what maximum or what minimum is liable to occur in a period of a given length.

The seasonal variation of rainfall may easily be obtained from records. The variations in annual rainfall are not so easily obtainable. It is desirable to put variations of rainfall on a comparative basis which eliminates absolute values and states things in relative values. The author of the paper made a strong point of that. This can be done in the matter of rainfall records by resorting to the principles of probabilities, and stating variations in terms of the coefficient of variation. This coefficient of variation has a definite meaning in the theory of statistics, and knowing the mean annual rainfall for a period of years, and determining the coefficient for that record of rainfall, it is a reasonably simple matter to determine with considerable confidence either the maximum or minimum rainfall that may be expected in a given length of time.

MR. CARL P. BIRKINBINE: The curtailment of this paper into a short presentation necessitated the omission of many statements. The thought intended was that the Ohio Valley rainfall in March, 1913, was the greatest quantity of rain on so large an area of which we have any record in this part of the country. Prof. J. Warren

Smith of the Weather Bureau in a paper on this flood said, "When the extent of the territory involved and the sequence of the storms is considered, no previous record exists which, in this section of the country, is in any way comparable with the rainfall of March 23–27, 1913."

The studies to which Mr. Longley refers should prove not only interesting but also of real value, especially as the precipitation records of but few stations extend back as much as fifty years. The obviation of damage by floods and the requisite storage reserves to maintain a supply during unusually low seasons are primary problems of water supply engineering. The occurrence of floods of various intensities in probable cycles has been recognized; but drought conditions generally leave no natural record, such as high water marks do of floods, and except where long time gauges have been maintained on streams, the data regarding these must be taken from precipitation records. Mr. X. H. Goodnough's recent discussion of a century of rainfall at New Bedford, Massachusetts, clearly showed the irregularity in intensity and occurrence of the periods of deficient precipitation, while other long time records can be plotted to indicate such facts. But any studies which will assist in making better scientific guesses at extreme conditions will benefit the profession, and hence the people served.

Many interesting facts and data regarding precipitation are buried in the files of engineering offices and scattered through records both public and private. It would be a gratification to the author if this paper would suggest more extensive publication, and perhaps later a systematic collection of the occasions and variations in precipitation. As Mr. Provost pointed out engineers should endeavor to obtain governmental publication of data in more useful form than at present, and as water works engineers and superintendents form a large proportion of the high grade coöperative observers, we can anticipate a closer harmony of operation with greater mutual exchange of data between the National Bureau and the profession.

Mr. Sidney K. Clapp: The paper by Carl P. Birkinbine is of extreme interest and represents an immense amount of research and compilation of very important data. It is so exhaustive that it seems unnecessary to discuss it in any detail. It may be interesting, however, to add a few words in relation to experiences in the

Catskill Mountain region, where some careful records have been kept for about thirteen years.

Attention may be drawn to the paper recently published by the New England Water Works Association, September, 1915, in which Mr. X. H. Goodnough has given many interesting and additional facts relative to New England rainfall. The conclusions reached in the above-noted paper and the subsequent discussion could only be repeated in this instance, and the discussion by Mr. George G. Honness covers practically all the work of the board of water supply in the Catskill region of New York.

There is no doubt that mountain condensation is a very important factor in runoff and is not often included in rainfall, although it may be very great and no doubt explains in part many high percentages of rainfall. Another important factor, not considered as often as it should be, is the question of evaporation and few, if any, new ideas have recently been proven, and it still remains a somewhat unknown quantity, although very important in many cases. That the personal equation enters into the results obtained is no secret, and results are often secured which need some explanation before being accepted. The difference in location of gauge, even in the same general neighborhood, acts in a very peculiar manner and care should be taken to determine all these facts before accepting any peculiar results as a record.

Snow is a very important factor in rainfall and the methods of obtaining the "equivalent rainfall" will bear inspection, and modify results in many instances. That it is important is shown on a very interesting view, taken March 2, 1914, showing sagging and broken telephone wires encrusted with ice and snow three inches in diameter.

Thunderstorms seem to be of local origin and vary in intensity in very limited areas, especially in the mountain regions. The results of these showers, combined with the ordinary rainfall data give very distorted figures which are sometimes misleading if taken for a short period.

Mr. Frederick J. Rehn, Assistant Engineer, Board of Water Supply of the City of New York, has compiled some very interesting figures in relation to influence of altitude on rainfall in the Catskill Mountains of New York, which are hereto appended.

Res. 1293
3/2/14

ALTITUDE INFLUENCE ON RAINFALL IN THE CATSKILLS

The location and distribution of rain gauges in the Catskill watersheds were made with a view to obtain the best average for each catchment area. The range of elevation is from 190 feet at Kingston to 2300 feet at Peekamoose. During the summer months Overlook Mountain gauge has an elevation of 3000 feet. On account of inaccessibility, during the winter season the gauge is located on the southerly slope towards Woodstock at an elevation of 900 feet. Due to the difficulty of obtaining a continuous record at very high altitudes, no extensive experiments have been had for the study of variations of rainfall and snowfall due to differences of elevations.

TABLE 1

Catskill watersheds rainfall. 8-year averages (1906–1913)

MARK	STATION	ELEVATION	RAINFALL	
BS	Brown Station	540	45.96	
Cl	Claryville	1750	47.57	
C	Cornwall	200		
Ed	Edgewood	1900	48.36	
Fn	Franklinton	1175	32.08	(7 yr. mean)
G	Grahamsville	900	44.80	
HaF	Haines Falls	1910	45.44	(7 yr. mean)
HiF	High Falls	200		
Hi	Highmount	1900	39.60	
HJ	Hopewell Jct	300		
K	Kingston	190	41.06	(7 yr. mean)
L	Lackawack	700	42.70	
LH	Lake Hill	1200	47.04	
Lx	Lexington	1440	36.93	
Mo	Moonhaw	1200	58.96	
NP	New Paltz	200		
OH	Oak Hill	700	34.51	(7 yr. mean)
OMt	Overlook Mt	3000	47.46	
Pk	Peekamoose	2300	58.33	
Pa	Phoenicia	750	46.58	
PV	Pleasant Valley	220		
Pr	Prattsville	1165	33.80	(7 yr. mean)
PH	Preston Hollow	850	33.28	(7 yr. mean)
S	Silvernails	380		
Sl	Slide Mt	1900	55.55	
Sn	Sundown	1000	44.63	
W	Walden	400		
Wo	Westerlo	1160	33.24	(7 yr. mean)
WH	West Hurley	565	44.25	(7 yr. mean)
WS	West Shokan	540	48.49	
Wm	Windham	1500	35.61	(6 yr. mean)

In the summer of 1907 two gauges were installed at practically the same location, one at Edgewood in the Esopus watershed at an elevation of 1900 feet, the other on top of Hunter Mountain at an elevation of 4000 feet. Synchronous records were kept for a period of 34 months, which gave a rainfall 5 per cent higher for the Hunter Mountain gauge. The style of gauge used at both stations was the standard Friez 8-inch United States Weather Bureau Gauge.

Isohyetal maps of the Catskill watersheds for the year 1913 and a composite map for the years 1906 to 1913 inclusive, show better than any wordy comparison the general effect of altitude on the distribution of rainfall. These maps show a well defined summit of rainfall corresponding to the mountain elevation summits forming the divide between the Esopus and Rondout watersheds, with a maximum fall of 60 inches in 1913. The influence of the divide between the Esopus and Schoharie watersheds also is very marked. Here Hunter Mountain and Overlook make their presence felt.

For the 8-year mean, 1906–1913 inclusive, the greatest difference in rainfall between two stations was 19 inches: Peekamoose, elevation 2300 feet, gave 58.33 inches; Highmount, elevation 1900 feet, gave 39.60 inches. Slide Mountain, elevation 900 feet, gave 55.55 inches; West Hurley, elevation 565 feet, gave 44.25 inches; Kingston, elevation 190 feet, gave 41.06 inches.

Table 1 gives list of rainfall stations, Catskill watersheds, their elevations and some data of the 8-year record as kept by the board of water supply. These data will support the well known fact that mountains do materially affect the distribution of rainfall, but are not sufficient to reach any conclusion as to what the difference might be for varying heights. If local thunderstorms could be eliminated the data would be in better shape for comparison upon which to base a conclusion.

MR. JOHN C. TRAUTWINE, JR.: In view of the very exhaustive character of Mr. Birkinbine's paper, I submit that it should be entitled "A Treatise on Precipitation," and published in book form.

The author has covered his ground so fully as almost to preclude discussion respecting the subject proper; but I venture to mention two related matters discussed by the author near the close of his paper, viz., the appearance of tidal phenomena in inland waters, and the effect of deforestation upon precipitation and upon runoff.

Engineering News recently described a case where the waters of a lake, not far from a tidal sea, underwent daily changes of level, corresponding, at least in a general way, with those of the neighboring tidal water; and the suggestion was offered that the daily (and apparently tidal) fluctuations of the lake surface might be accounted for by hypothesizing the presence of an impervious and flexible stratum (as a clay bed) between the two waters, said stratum transmitting the pressure changes, due to ebb and flow, from the sea to the inland water, much as an india rubber diaphragm might do.

The speaker's impression has been that the old time faith in the effect of deforestation upon rainfall has been seriously undermined by recorded facts, and that a prominent official of the Weather Bureau recently denied the effect of deforestation even upon runoff.

MR. CARL P. BIRKINBINE: Replying to Mr. Trautwine's discussion; the variations in inland lakes referred to in the paper were those due to climatic conditions and the resultant irregularities of precipitation. The present Great Salt Lake and the Otero soda basin are the most striking examples in this country of the desiccation of large bodies of water, while other instances have been studied in Europe and Asia. The fluctuation in lake levels within relatively few years was related to climatic conditions by Brückner, and later investigations have contributed much along the same lines. Dr. Huntington found a close relation between the levels of Owens Lake in California and the growth of adjacent trees.

As to the matter of precipitation and runoff being affected by deforestation and agricultural development, the point brought out in regard to precipitation includes two separate ideas. One that the different temperature conditions between forest and open land may alter the character of the precipitation, that is from rain to snow or vice versa. In this connection there has recently been published a paper claiming a different depth of snow fall for forested areas from that for open ground; although as the effects of ground temperature, ground moisture and wind are to be considered, the conclusions of the paper are not yet definite. It has also been claimed that land under cultivation permits higher evaporation from the soil, thus extending the area of condensation, although this would need to cover a large area to be appreciable.

It is true that a former high official of the Weather Bureau strongly stated that deforestation did not affect the runoff, but I do not accept this as a general statement. Records of stream flow both maximum and minimum, the visible signs of erosion on bare ground, the slow melting of snow in shaded areas, the reduction of intensity offered by leaves and branches during severe downpours, the greater porosity of forest humus and the fact that it does not freeze deep, and the more uneven and obstructed floor of the forest as compared to bare hill or field, cannot fail to have the effect of stabilizing runoff, and this view is generally shared by those who have studied the records and conditions, especially in this country where deforestation generally clears the ground of all growth.

MR. NICHOLAS S. HILL, JR.: In the preparation of this paper Mr. Birkinbine has confined himself quite closely to the first half of his subject as set forth in the title. That is, he has treated very fully the subject "Variations in Precipitation" and touched rather lightly upon their "Effect Upon Water Works Engineering." In this he has been actuated by a desire to be brief. Under the circumstances, the writer deems it proper that the second half of the subject should be brought out somewhat more fully in the discussion. He will, therefore, confine himself largely to a discussion of this phase of the subject, and the more especially so as Mr. Birkinbine's comprehensive treatment of the "Variations in Precipitation" leaves comparatively little to be said upon this subject by way of criticism, amplification, or comment.

Studies of hydrologic and meteorological phenomena, familiarity with laws governing their occurrence, so far as these are known, and an understanding of the nature and influence of the various conditions by which these phenomena are affected, are of great interest and value to the practicing engineer.

To the civil, hydraulic and sanitary engineer a thorough understanding of these phenomena, with particular reference to the causes, extent, mode of occurrence, distribution and variations in precipitation, in the territory in which he practices his profession, is indispensable.

His interest extends to nearly every phase of this branch of the science of meteorology. The extent, mode of occurrence, seasonable distribution, and variations in precipitation are of direct interest to him in many ways. Torrential rains erode embankments and the slopes of cuts unless these have been designed to withstand their action. In areas in which such rains occur, particularly if they may be accompanied by high winds, the walls of masonry buildings must be more substantially constructed, and more thoroughly waterproofed to enable them to resist the penetration of moisture, than would be the case elsewhere. Heavy snowfalls impose considerable loads upon roofs, which must be designed to resist safely the maximum stresses which may result from this cause. Snowdrifts may seriously impede the operation of steam and electric railways unless suitable snow brakes are designed and installed. In some localities hail storms may occur, of sufficient intensity and frequency to justify the engineer in incorporating in his designs special provisions for resisting their damaging effects. Severe

storms of wet snow and sleet will exert an influence upon the design of many engineering structures, particularly upon overhead wiring systems, and exposed mechanisms, and devices of all kinds. Even the occurrence of protracted dry spells may influence the drafting of engineering specifications and lead to the introduction of clauses requiring that concrete be wet at intervals following the removal of forms, and that brick be well moistened before being laid.

The above are only a few of the many direct ways in which the precipitation characteristics of a territory may exert an influence upon design.

In many of the drainage problems, the engineer's interest in the amount, time and mode of occurrence, and particularly in the probable intensity of precipitation during a moderate interval, is hardly less direct than in the cases above mentioned. The required capacity of storm water sewers, culverts and drains at any point depends upon the maximum volumes of surface runoff which may reach that point simultaneously. With any given tributary area, that is, with an area, the size, shape, soil character and topographical features of which are fixed, this total volume will depend directly upon the most severe conditions which may occur as regards precipitation. In cases of this kind, records of intense storms, of which Mr. Birkinbine presents a considerable number, are of great value, and usually form the only basis for computing intelligently the maximum runoffs and the required capacity of the structure. Where past experience is the only guide to the future, it is important that this experience be recorded, and the records be easy of access. The duration of storms of varying intensity is also of prime importance. If the catchment area is of very limited extent, as, for example, a roof, the maximum recorded precipitation for a one or two minute interval may impose a more severe tax upon the capacity of the drains than would the maximum recorded precipitation for a fifteen or a thirty minute interval. With the larger area tributary to a culvert or catchment basin, the reverse will be true, for in this case, with very intense precipitation during short intervals, the depositions in the immediate vicinity of the culvert or basin pass off before the arrival of equally intense precipitation from parts more remote, and these, upon reaching the culvert or drain, are combined with later and less intense depositions upon areas nearby. The critical period of intense precipitation, i.e., the period during which the maximum precipitation will control the design,

varies with the physical features of the area drained and must be determined for each case. The value of data recording intense storms of varying duration is, therefore, apparent. The engineer may also be obliged to consider whether or not an intense storm may occur when the ground is still frozen, thus contributing to a high per cent of runoff, and whether its occurrence coincidentally with melting snows from earlier depositions is sufficiently probable to warrant being taken into account. In all such questions past records, if of long duration, form the best guide.

In addition to instances already mentioned, there is a very important group of problems in which the engineer's interest in precipitation phenomena, though indirect, is very keen. Reference is here made to that large class of problems involving the yield of surface and underground catchment areas and the design of works looking to its utilization and control. Here the interest of the engineer is primarily in questions of runoff and percolation, of the amount and variations in the probable yield of the surface and underground sources of supply rather than in the amount and variations in precipitation. He is interested in the rainfall only because it is the source and cause of the yield.

The problems falling within this group may be divided broadly into three classes:

(a) Those in which the probable maximum hourly, daily, weekly or monthly runoff must be known;

(b) Those in which the probable minimum daily runoff is of importance, and

(c) Those in which the average daily yield by months, consecutively, or in chronological order, for a long period, of, say forty years, is desired.

Class (a) embraces problems of dam design, the proportioning of spillways and waste way channels, the protection of structures against floods, flood prevention, the regulation and control of the regimen of streams, the design of storm water sewers and drains, and the like.

Class (b) may be instanced by the problem of the disposal of sewage and sewage effluents by dilution in inland waters.

Class (c) embraces those hydrologic problems connected with water supply, hydraulic power development and irrigation which involve determination of the average, and safe, or minimum, yield of surface and underground catchment areas with various amounts

of storage, the storage required to produce a desired yield, and the like.

The problems of class (a) are very similar to the drainage problem previously referred to, except that the conditions are here far more complex because of the size, and of the variable topographical and geological characteristics of the catchment area considered.

Although Mr. Birkinbine has mentioned many notable exceptions, the heavy floods in north temperate regions frequently occur in the spring of the year, when the soil is saturated by the precipitation of the preceding fall and winter, the partly frozen ground is favorable to a high percentage of runoff, and melting snow and ice contribute largely to its volume. Under these circumstances it is readily seen that the runoff in which the engineer is primarily interested will bear a very indefinite relation to the cotemporaneous precipitation, and anything approaching accuracy in the estimation, from precipitation records alone, of the probable maximum flood flow on a given catchment area will prove impossible.

Similar difficulty is experienced in attempting to estimate the probable minimum runoff, from precipitation records alone. On some sheds of considerable size the stream flow may entirely cease for several consecutive weeks. Another shed not many miles distant may exhibit a well sustained, or even heavy, dry weather flow under practically identical conditions of rainfall. Topographical and geological conditions on the watershed exert an important influence on the minimum runoff to be anticipated therefrom. The runoff from small flashy sheds having steep slopes, sparsely wooded, with limited ground water storage, and unaffected by springs, will respond well to variations in precipitation. Other sheds nearby may have moderate slopes, porous soil and considerable wooded areas. The soil of these areas may be blanketed with leaf mold, which absorbs the moisture of heavy rains like a sponge, and, being well shaded by deciduous trees with a resulting low evaporation, may have the effect of a storage reservoir. Such a shed will show a lower maximum and a much higher minimum runoff than will a flashy shed under the same conditions of rainfall. The presence of springs, too, may exert a very marked influence in sustaining the dry weather flow, and this is a factor for which it is practically impossible to apply a reasonably accurate correction without actual gaugings.

A study of the following tables will be illuminating as regards the marked differences in runoff per square mile which may occur

on watersheds in the same section of the country under closely similar conditions of precipitation.

The geographical centers of the two Pennsylvania sheds in table 1 are only 25 miles apart; and of the two New York sheds about 60 miles apart. The Pennsylvania sheds are about 125 miles distant from the New York sheds.

The very high yield of the Little Lehigh has been determined, from personal study and inspection of the shed, to be largely attribut-

TABLE 1

Differences in runoff per square mile, during a dry month on nearby watersheds under closely similar conditions of precipitation

(1) NAME OF WATERSHED	(2) AREA SQUARE MILES	PRECIPITATION SEPTEMBER, 1914		(5) NATURAL AVERAGE RUNOFF IN THOUSAND GALLONS DAILY PER SQUARE MILE SEPT., 1914	(6) PER CENT OF SEPTEMBER RUNOFF TO SEPTEMBER RAINFALL
		(3) Inches in depth	(4) Thousand gallons daily per square mile		
					per cent
Croton River at New Croton Dam, New York.....	360.4	0.32	183	95	51.9
Esopus Creek between Ashokan Dam and Glenerie, New York.....	172.5	0.56	322	142	44.1
Pohopoco Creek near Mauch Chunk, Pa.....	110.0	0.50*	290	260	89.6
Little Lehigh near Allentown, Pa.....	98.0	0.28†	162	581	358.6

* United States Weather Bureau Statistics, East Mauch Chunk, Pa. = basis.
† United States Weather Bureau Statistics, Allentown, Pa., = basis.

able to springs, which also affect the flow of the Pohopoco, but to a lesser extent. Observe that whereas in a month of low rainfall the per cent of runoff to rainfall on the Esopus is one-seventh less than on the Croton, the average per cent of runoff to rainfall during the seven years, 1906 to 1912, is one-third greater on the Esopus than on the Croton. The high average annual percentage yield of the Esopus as compared with the Croton is not attributable to any single cause, and was, in fact, not fully anticipated by the eminent engineers who studied this shed prior to its selection as the source of a supplementary supply for New York City.

If large difficulties attend the estimation, from precipitation records alone, of the probable maximum and minimum runoff or yield of a given catchment area, these difficulties sink into insignificance compared with those which arise when, as in the problems of class (c), the data desired are chronological records of runoff, consecutively by months, over periods sufficiently long to embrace all probable extremes of flood and drought. That this must inevitably be true is apparent at once from a mere statement of the complex relationship subsisting between precipitation; evaporation, including transpiration; percolation, and stream flow.

The immediate source of every supply of fresh water, whether surface or underground, is the precipitation upon the surface or underground catchment area tributary thereto. The ultimate source is, of course, the sea. The phenomenon of precipitation may be briefly described as follows, evaporation of water, through the agency of the sun's heat, into aqueous vapor; transportation by winds of clouds so formed; condensation resulting from lowered temperature, and precipitation.

This statement of the phenomenon suggests that, other things being equal, the following factors contribute to high precipitation:

1. Nearness to the source, that is, to the sea, or other large body of water.

2. Geographical position in the path of prevailing winds from the direction of the source.

3. Position in the average track of climatological disturbances, barometric depressions, or storms.

4. Position with respect to prominent topographical features, such as mountain ranges, particularly those running at right angles to the direction of the rain bearing winds, and which contribute to a lowering of temperature, and hence to condensation and precipitation.

Of the precipitation deposited upon the earth, part runs off directly into the streams and augments their volume of flow. The percentage of the total deposition which thus runs off directly varies with the form and intensity of the precipitation, the steepness of the slopes on which it falls, the composition of the soil as regards porosity and its condition as regards freezing, the surficial condition of the catchment area as regards snow, vegetation and other elements which may accelerate or retard the precipitation in its course toward the streams.

Part is reconverted into aqueous vapor by evaporation from water or land surfaces, or by transpiration from forests and vegetal coverings of all kinds. The percentage of the total deposition thus lost varies with the form and intensity of the precipitation, with the temperature, with wind velocities, with relative vapor pressures, with the extent of water surface, extent and character of vegetation, season of the year, degree of saturation of the soil, and so on.

Part percolates into the ground. The percentage of the total deposition which is thus temporarily or permanently withheld from the stream varies with the porosity of the soil, with its slope and surficial condition, its condition as regards freezing and with its degree of saturation.

Of the portion which percolates into the ground, a large part eventually reappears in the streams, sustaining their flow during the months and years of low precipitation. The amount by which the stream flow is thus augmented varies with the composition of the soil as to porosity, its condition as regards freezing, and the state of depletion of the ground water storage.

The runoff in a given month may considerably exceed the total precipitation on the catchment area during that month. In another year the runoff for the same calendar month may be very much less than the corresponding precipitation. For the same annual rainfall, the annual runoff occasionally varies by nearly 100 per cent on the same stream.

A layman might infer from the foregoing remarks that runoff, after all, bears a very indefinite relation to cotemporaneous rainfall, and, therefore, that a knowledge of the amount of, and variations in, precipitation is of slight use as a means of judging the probable amount of, and variations in, runoff. This is not the case. Notwithstanding the extreme complexity of the relationship between precipitation and runoff, they do bear to each other the definite relationship of cause and effect. The relatively large number of precipitation records of considerable duration, as compared with the fragmentary and brief runoff records usually available, has led to a number of ingenious and able attempts to express this relationship by means of formulae.

The most recent of these efforts is fully described in a valuable 100 page paper entitled "Computing Runoff from Rainfall and Other Data" presented before the American Society of Civil Engineers on April 21, 1915. The paper is by Adolph F. Meyer,

M. Am. Soc. C. E. A similar attempt was made twenty years ago by C. C. Vermeule, then Topographer and Consulting Engineer of the Geological Survey of New Jersey, and the results published in his "Report on Water Supply, Water Power, the Flow of Streams, and Attendant Phenomena," forming Vol. III of the Final Report of the State Geologist, 1894. Messrs. Justin,[1] Babb,[2] Rafter,[3] Newell,[4] and others have also made investigations along these lines.

Such formulae do not form a reliable means of building up a chronological monthly record of runoff from precipitation records alone. Their employment is strictly limited to sheds for which long and accurate monthly meteorological records of precipitation, temperature, etc., are available. Except through the use of arbitrary coefficients to be assumed by the computer they do not provide corrections for characteristic differences in the topographical configuration and shape of the drainage area, geological formation, vegetal covering, springs, etc., any or all of which may exert a marked influence upon the relationship which the formulae aim to express. They are of more value in cases where a long and reliable meteorological record exists in conjunction with a fragmentary or brief runoff record. Under these circumstances the runoff computed with tentative coefficients may be compared with the corresponding actual runoff where known, and the first assumption as to the proper water shed coefficients modified in the light of this comparison. As a rule, their authors do not make extravagant claims as to the usefulness of formulae of this kind. Mr. Meyer has this to say with regard to his own results:

> Let it be understood at the outset, that the writer does not claim to have discovered a method of computing daily or even monthly runoff from rainfall and other physical data which obviates the necessity for stream measurements. He believes, however, that he has found a method of computing the annual runoff from widely different watersheds with considerable accuracy, and of computing a reasonable distribution of such runoff through the various months of the year for most of such watersheds.

With regard to the efforts of his predecessors, he says:

> Although recognizing the able manner in which the subject of stream flow has been discussed in the technical press during past years, the writer cannot

[1] Transactions Am. Soc. C. E., vol. lxxvii, p. 346.
[2] Transactions Am. Soc. C. E., vol. xxviii, p. 323.
[3] Water Supply and Irrigation, Paper No. 80, U. S. Geological Survey.
[4] Fourteenth Annual Report, Part 2, 1892-1893, U. S. Geological Survey.

refrain from expressing the belief that the relations between rainfall and runoff indicated by the curves and formulæ just referred to, are, in a varying degree, generalizations, which bring out class likenesses, but obscure the individual characteristics of runoff from different sheds resulting from differences in the character and distribution of the rainfall, and the effect of temperature, vegetal cover, topography, soil and subsoil on the disposal of rainfall.

In the North Atlantic States resort is seldom had to methods of computing runoff from rainfall by formula. Engineers in the East are fortunate in the possession of five records of cotemporaneous rainfall and runoff, some of which approach the ideal as closely as can be expected with streams, the natural regimen of which has been altered by artificial storage. These records have been maintained for many years by the water departments of Boston, New York and Philadelphia. Reference is made to the Sudbury, supplying Boston, drainage area 75.2 square miles with precipitation and runoff records for forty years from 1875 to date; to the Croton, supplying New York City, drainage area 360.4 square miles with precipitation and runoff records for forty-seven years from 1868 to date; to the Tohickon, supplying Philadelphia, drainage area 102.2 square miles with precipitation and runoff records for twenty-nine years from September 13, 1883, to December 31, 1912; to the Neshaminy, supplying Philadelphia, drainage area 139.3 square miles with precipitation and runoff records for twenty-eight years from June 10, 1884, to December 31, 1912; and to the Perkiomen, supplying Philadelphia, drainage area 152 square miles with precipitation and runoff records for twenty-eight years from August 20, 1884, to December 31, 1912.

In this locality the usual practice is to adopt one of these long continued records of monthly runoff as a standard or base record, in the actual solution of problems of storage and of average and safe yield. Such fragmentary records of rainfall and runoff as may exist on the local shed under consideration are then used as a guide to the judgment in the selection of corrective factors to apply to these standard records to adapt them to local conditions as regards precipitation, and as regards such characteristic peculiarities of the local drainage areas as may influence the amount and variations of runoff. For this purpose the fragmentary local records are invaluable.

In general, it may be said that the ideal data with which to attack problems involving estimates of the maximum, minimum, average,

or safe yield of surface or underground sources of supply; the number of horse power hours available on water during an average year; the effect of storage on each of the above, and the like, are as follows:

(a) Continuous records of monthly precipitation at a number of representative points on the watershed for a period of forty years.

(b) Continuous records of natural average daily runoff per square mile of watershed by months for a cotemporaneous period of forty years.

A forty year period is mentioned because experience indicates that it takes thirty to forty years to secure an accurate measure of the mean annual rainfall at any given place. Such a record is likely to include all extremes of flood and drought which may occur, and it

TABLE 2

Differences in average annual runoff per square mile, during seven consecutive years, on nearby water sheds under practically identical conditions of precipitation

(1) NAME OF WATERSHED	(2) AREA SQUARE MILES	(3) PERIOD CONSIDERED	(4) AVERAGE ANNUAL PRECIPITATION		(5) AVERAGE ANNUAL RUNOFF IN THOUSAND GALLONS DAILY PER SQUARE MILE	(6) PER CENT OF RUNOFF TO RAINFALL
			Inches in depth	Thousand gallons daily per square inch		
						per cent
Croton River at New Croton Dam, N. Y....	360.4	1906–1912	47.99	2285	10.70	46.8
Esopus Creek at Ashokan Dam.....	255.0	1906–1912	47.99	2282	14.15	62.0

is reasonable to conclude that, to secure the true means and extremes of runoff, a record of similar length must be available.

The above facts so far as they relate to rainfall are well exemplified in table 2 of Mr. Birkinbine's paper, from which it is seen that the averages of precipitation at Philadelphia during the forty-four years from 1871 to 1914 compare extremely well month by month with the corresponding averages for the entire ninety-four year period of record. Needless to say, such complete data are never found on streams the development or utilization of which is proposed.

In his paper entitled "Computing Runoff from Rainfall and Other Data," to which reference has already been made, Mr. Meyer states: "Precipitation and temperature are being observed in the United

States at more than 5000 stations. Stream measurements are being made by federal and state authorities, and private parties, together, at about one-fourth as many stations." Thus there is in the United States at the present time about one rain gauging station for every 600 square miles of territory and one stream gauging station for every 2400 square miles. The runoff records are for the most part of short duration.

Not long ago the writer was called upon to estimate the safe yield of a watershed 110 miles in extent in one of the most densely populated of the original thirteen states. There was no point on the shed at which precipitation records had ever been maintained, and although two water companies and one power user of considerable size had obtained their supplies from this stream for many years, no flow measurements of any kind were available. Such cases are by no means uncommon.

The precipitation records which exist are for the most part reliable and many of them cover periods of considerable length. Mr. Birkinbine notes ten places, Boston, Albany, Providence, Philadelphia, Charleston, New Orleans, Cincinnati, St. Louis, Fort Leavenworth and St. Paul, at which records are available for periods of from seventy-five to one hundred years. All of them are continuous except that at New Orleans which is broken from 1860 to 1868. To these may be added:

	years
New Bedford, Mass.	100
Waltham, Mass.	90
Lowell, Mass.	88
Rochester, N. Y.	86
New York City, N. Y.	79
Amherst, Mass.	78
Worcester, Mass.	74
Cambridge, Mass.	74
Newark, N. J.	72

According to Mr. X. H. Goodnough, Chief Engineer, Massachusetts State Board of Health, reliable precipitation records in New England date back to 1749. (See exhaustive paper entitled "Rainfall in New England" in *Journal of New England Water Works Association* for September, 1915.) Those at Charleston, S. C., date back to 1737. Records exceeding forty years in length are quite numerous throughout the United States. It is seldom, however, that more than one such record will be found on or near watersheds of moderate extent.

Attention should be drawn to the fact that large errors may result from applying the district normal to individual watersheds, or from assuming that a single record on or near a drainage area is representative of the average precipitation on the shed as a whole. This holds true even for sheds of limited size. On Esopus Creek above Ashokan Dam with a drainage area of 255 square miles, the recorded rainfall at the Moonhaw Lodge gauging station of the Board of Water Supply of the City of New York has been 50 per cent greater over a period of several years than at the Highmount Station located in the same shed and only a few miles away. At the time this stream was first talked of as a future source of supply for New York City, the nearest extensive precipitation record was that at Albany, 50 miles away. There was also a fragmentary record at Kingston, 12 miles below on the same stream, and a few records at three points, Windham, Griffins Corners and Mohonk Lake, lying just outside the border line of the shed. There was no rain gauging station on the shed itself at that time. The district normal for Albany and points on the Esopus watershed as read from the chart "Normal Annual Precipitation in the United States, 1870–1901," see plate 2 of Mr. Birkinbine's paper, is 40 inches. The actual average annual precipitation at Albany during the eighty-seven years from 1826 to 1912 was 38.15 inches. Subsequent to 1905 some ten rainfall gauging stations were established on the Esopus by the board of water supply. The average annual precipitation on the shed for the seven years 1906 to 1912 was 47.94 inches with a variation in the average as between stations of from 39.61 inches at the Highmount Station to 58.63 inches at the Moonhaw Lodge Station. The average of all stations (47.94 inches) for this period of seven years was, therefore, 20 per cent higher than the district norm. At Albany during these same seven years the average annual precipitation was only 30.75 inches or 23 per cent lower than the district norm. At the three points lying just outside the border line of the Esopus shed, Windham, Griffins Corners and Mohonk Lake, the average for the seven years was 40.61 inches, and at Kingston for the six years 1907 to 1912 it was 41.19 inches, or just a little above the district norm. There is no doubt whatever that the application to the Esopus water shed, in unmodified form, of the district normal, of the long Albany record, of the fragmentary Kingston record, or of values obtained at the three gauging stations near the border line of the shed would have produced an estimate of precipitation 20 per cent to 40 per cent below the true values for this shed.

The case illustrates well the desirability of long records well distributed over the drainage area under investigation. Under these conditions data obtained at gauging points on each of the principal branches of the main stream may be grouped and averaged, and the results weighted according to the extent of the subareas to which they apply. It must not be inferred, however, that such records are indispensable to the drawing of reasonably accurate conclusions as to the average amount of precipitation to be expected on a given shed. Many of the variations in precipitation as between points on and near the Esopus watershed are understandable and to have been anticipated in the light of the known laws affecting the occurrence of precipitation phenomena. To the extent that this is true the case emphasizes, rather, the importance of a thorough knowledge of these laws on the part of those who have occasion to utilize such records.

As has been previously stated, runoff records in the United States are for the most part fragmentary and of short duration. Those which exist are less accurate than precipitation records, though, of course, more dependable than runoff estimated from the precipitation. The greater part of these records are obtained by gauging the flow of streams at selected points by means of a current meter. Measurements are made at different stages of the stream from low flow to high water, and a rating curve prepared. With this curve established the subsequent discharge may be estimated from the stage of water in the stream which is usually observed once or twice daily. Aside from the sources of error inherent in the method one or two others may be noted:

(a) The method aims to give the daily quantity of water passing a given point. To be useful this must, ordinarily, be reduced to terms of runoff per square mile of watershed per day. In districts which have been mapped out by State or Federal geological surveys, the total drainage area above the gauging station may readily be ascertained. But on many streams considerable quantities of water, of variable and unknown amount, are abstracted above the point of gauging and devoted to irrigation and water supply uses. Frequently, too, there are water power developments on these streams which, while they do not actually abstract any considerable volumes of water, greatly change the regimen of the stream through pondage. A ten hour power with small pondage would be likely at some seasons to draw fully upon this pondage during the ten working hours, thus sending down abnormally large quantities of water at the very times during which the stage of the stream at the gauging point was being observed. If the pondage were large it might, and probably would, be operated in such a way as still further to vitiate the natural flow of

the stream below the power site. It is manifestly impossible for the government bureaus in charge to apply proper corrections in cases of this kind, and it is equally impossible for the engineer who has occasion to use their published data to do so.

(b) The rating curve mentioned above is determined under and applies only to open water conditions. In northern latitudes, streams may be frozen over for several months of the year. To determine with reasonable accuracy the daily discharge of a stream under ice conditions, frequent gaugings by current meter are required. This is often difficult because of the formation of needle ice. It is always expensive, usually prohibitively so. Thus the reported discharge during the winter months may be quite undependable.

(c) In some cases, the flows at high stage can be estimated only roughly because of the stream overflowing its banks, or for other reasons.

The official runoff records of so important a stream as Esopus Creek afford examples of all three of the sources of error mentioned above, and the possibility of their existence must be recognized and allowed for in utilizing these records in conjunction with those of precipitation.

Speaking generally of Mr. Birkinbine's paper, it may be said that he has treated his subject, especially that part of it which deals with "Variations in Precipitation," in a very comprehensive and able manner, and in so doing has performed a valuable service. In the view of the writer, if the paper is open to adverse criticism in any respect, it is upon counts so minor as to be unworthy of mention.

Mr. Carl P. Birkinbine: Mr. Hill's able article is welcomed, and he has correctly surmised the basic idea of the compilation of the paper. The desire was to keep its length within proper bounds and refer to the important and intimate relation between precipitation and water works engineering; and by references and data on the former subject, supplemented by brief comment upon the interrelationship, to bring out more detailed discussions of some of the many phases of hydraulic as well as general engineering, which are to be studied in connection with precipitation conditions.

Mr. Hill has emphasized the value and necessity of familiarity with hydrologic and meteorological phenomena, and urges the accessibility of important records. The reference to drought conditions demanding greater precautions during construction of cement and brick work, suggests other mention of the direct or resultant effects of precipitation conditions upon engineering constructions. Such are: coffer dam building, excavation of wet or sun baked earth, flooding of open cuts by direct rainfall or percolated water, seepage into tunnels and shafts, earth slips and slides of satu-

rated soil, quicksand troubles, expansion or shrinkage of timber and ropes, hauling on wet earth roads, ice coatings on materials and roadways, heating of large pipes by sunshine, shorter number of daylight hours because of various storm conditions, reduced working time and efficiency of workmen in rainy periods, etc.

The occurrence of heavy floods in the spring in the north temperate region is, for some streams, almost annual, and this is predominently the season of maximum high water. The references in the paper to maximum floods occurring because of rainfall alone were inserted to emphasize the fact that the spring runoff may be exceeded by that due to heavy summer rains on the watershed or to severe and successive thunderstorms on a small area. The first type of occurrence produces high runoff by soil saturation, while the second form often creates a quick and heavy surface discharge because of the hard condition of the ground and the excessive deposition in a period of short duration.

Tables 1 and 2 of Mr. Hill's discussion present interesting data, especially when studied with the detailed facts. In table 1 the wide range between Pohopoco Creek and the Little Lehigh watershed, caused by the flow of springs, is, to quote Mr. Hill, "one of the best examples as to how underground water conditions may change computations based on rainfall records."

The discussion of the complex relation between rainfall and runoff was purposely omitted from the paper to keep down its length, but Mr. Hill's clear and brief discussion of this, which may be summed up in his sentence, "That they bear to each other a definite relation to cause and effect," is valuable.

The relative accuracy of periods of different lengths have been shown by tables and curves, compiled by various authors; but in using such averages it is important to know the conditions of irregular periodic variations which occurred in the interval; for a period of several decades may include or just miss a cycle of great or small precipitation whose duration is more than one-third of the total period.

Mr. Hill has shown by specific examples the desirability of long records well distributed over the area, and how variations between stations are explainable. The late Emil Kuichling, in a private discussion, forcibly expressed his disapproval of the unsystematic location of rain gauges in the United States, and advocated having these placed at the corners of areas 20 miles square covering the

entire country. The writer does not concur in such a rigid location because of topographic and natural conditions and meteorological phenomena, but points out that the present stations in the United States, being both official and coöperative, are not balanced with respect to area, altitude, wind direction, storm paths, proximity to water surfaces and mountain ranges, latitude, etc. Many important data are obtainable from the few localities which maintain several gauges in proximity, especially when, as at Philadelphia and New Orleans, these recorded intensities during the various intervals of precipitation, and more of such gauges are also desirable. Only time can add to the present small number of extended records, but engineers can urge and often contribute to the location and operation of new gauges so placed as to add to available data. The government records of stream flow, precipitation and other meteorological conditions have contributed largely to many important engineering studies. The engineering associations would be warranted in urging in unison larger appropriations from state and federal governments for this work, because the engineer works for the good of the people; and their sincerity will be emphasized by individual efforts to maintain coöperative stations and give the data collected to the Weather Bureau, which would gladly publish it for the benefit of all.

The author appreciates the interest in the subject matter shown by the various contributors to the discussion, and feels that their careful analyses of the paper and the additional information supplied by them will be of great value to those interested in the subject.

MR. ELLSWORTH HUNTINGTON (by letter): Mr. Birkinbine's admirable paper brings out one point with special clearness. The most serious disasters arise from failure to prepare for extremes greater than have hitherto been recorded. The longer the meteorological record the greater the extremes which it shows. This is almost universally true, but in most places accurate records have been kept only about half a century or less. Will it continue to be true as the length of the records becomes greater? Suppose that we know what has occurred in a given region as to rainfall, floods, droughts, high winds and other climatic elements for a hundred years. If the margin of safety is based on records of such length, are we certain that our engineering works will stand any test that is likely to come to them?

The answer depends upon our conclusions as to climatic changes

in the past. Although exact numerical data are scanty, they suffice to show that there is a possibility that our water works, power-plants and other engineering projects may at any time be subjected to a strain greater than is indicated by the records of the past fifty or a hundred years. Let us take one special period, from the end of the thirteenth century, say about 1290 A.D., to the middle of the fourteenth, and see what happened then. At that time the level of the Caspian Sea rose with unparalleled rapidity. Previously the water had stood low enough so that a caravansérai was built on what is now the floor of the sea, at least 15 feet below the modern datum level. In the winter of 1306–1307 the water, after some years of rising, had reached a certain holy grave, well known even now, which is 37 feet above the datum level. That is, within a comparatively short period the level of this hugest of lakes rose at least 52 feet, the last part of the rise being very rapid. The natives, not perceiving any other cause, attributed the rise to the closing of a mythical underground outlet by earthquakes. The true cause was almost surely a sudden increase in rainfall.

If the Caspian Sea were the only line of evidence we might doubt this conclusion. Fortunately evidence from widely scattered parts of the world unites in showing that the period in question was a time of extraordinary climatic disturbance. For instance at Lop-Nor, an enclosed salt lake in the deserts of western China 2000 miles east of the Caspian Sea, a similar event took place. A Chinese chronicle relates that in the time of Chi-ta, who ruled from 1308 to 1311 A.D., the lake streamed over its banks, rising with great rapidity and overwhelming the Dragon Town of Lung-shong, which had formerly stood not far from its banks. Evidently we have here the same sort of catastrophe as at the Caspian Sea, but a few years later.

In Europe also this period was marked by unusual climatic stress. For instance, between 1296 and 1430 A.D., there occurred the four coldest winters on record in northwestern Europe. The facts are recorded in numerous old chronicles which have been studied by Norlind[1] and others. These documents state that in those winters the Baltic Sea froze to an extent unknown either before or since. The year 1296 was extraordinarily severe, but 1306 was worse, and 1323–24 was the severest winter ever known. In 1408 the Baltic

[1] A. Norlind, Einige Bemetkungen über das Klima der historischer Zeit.; Lunds Univ. Arsskrift. N. F. Afd. 1, and Vol. 10, No. 1. Lund 1914, 53 pp.

Sea froze again, but not so much as in 1323–24, when horses and sleighs crossed the ice from Germany to Sweden, an event never known in our day.

The conditions of the fourteenth century in northwestern Europe have been well summed up by Pettersson, Director of the Swedish Hydrographical Bureau. He says that the century presents

a record of extreme climatic variations. In cold winters the rivers Rhine, Danube, Thames, and Po were frozen for weeks or months. On these cold winters there followed violent floods, so that the rivers mentioned inundated their valleys. Such floods are recorded in 55 summers in the fourteenth century. There is of course, nothing astonishing in the fact that the inundations of the great rivers of Europe were more devastating 600 or 700 years ago than in our days, when the flow of the rivers has been regulated by canals, locks, etc., but still the inundations of the thirteenth and fourteenth centuries must have surpassed anything of the kind that has occurred since then. In 1342 the waters of the Rhine rose so high that they inundated the city of Mayence and the Cathedral "as far as a man's waist." The walls of Cologne were flooded so that they could be passed by boats in July. This occurred also in 1374 in the midst of the month of February, which is of course an unusual season for disasters of the kind. Again in other years the drought was so intense that the same rivers, the Danube, Rhine, and others, nearly dried up, and the Rhine could be forded at Cologne. This happened at least twice in the same century. There is one exceptional summer of such evil record that centuries afterward it was spoken of as "the old hot summer of 1357."[2]

Pettersson goes on to speak of two phenomena pertaining to the ocean as distinguished from the land. On these the old chroniclers lay great stress.

The first is the great storm-floods on the coasts of the North Sea and the Baltic, which occurred so frequently that not less than 19 floods of a destructiveness unparalleled in later times are recorded from the fourteenth century. The coast line of the North Sea was completely altered by these floods. Thus on January 16, 1300, half of the island of Heligoland and many other islands were engulfed by the sea. The same fate overtook the island of Borkum, torn into several islands by the storm-flood of January 16, which remoulded the Frisian Islands into their present shape. This flood is known as the "great man-drowning." On November 1, 1304, the island of Ruden was torn asunder from Ruden by the force of the waves. Time does not allow me to dwell upon individual disasters of this kind, but it will be well to note that of the nineteen great floods on record eighteen occurred in the cold season between the autumnal and vernal equinoxes.

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[2] O. Pettersson: Climatic Variations in Historic and Prehistoric Times. Hydrographical-Biological Institute, Stockholm, 1914.

The other phenomenon to which Pettersson refers is the freezing of the Baltic Sea.

It will be noticed that the climatic extremes here described indicate that the winters were extraordinarily cold upon the lands, while storms of exceptional severity prevailed over the North Sea and occasionally penetrated inland. The summers on the continent were marked by storms of unprecedented severity alternating with intense droughts. In the North Sea region the summers must have been unusually wet. In England excessive moisture caused the crops to decline to such an extent that where in certain regions 12 bushels had been reaped on an average in the thirteenth century only 8 bushels were reaped in the period from about 1320 to 1350. In Norway similar disasters took place, and the crops declined so badly that the crown revenues sank 60–70 per cent. Far away in Greenland ice came down on the west and south coasts, and navigation was greatly impeded. Other disasters also took place, all apparently due to climatic severity. Thus the Norsemen seem to have been driven from Greenland.

In North America, as well as in Asia, Europe, and the great island of Greenland, there was a period of sudden climatic stress at this time. The curve of growth of the great Sequoia trees of California, as given in Mr. Birkinbine's figure 41, shows that between 1290 and 1350, A.D. the trees suddenly began to grow rapidly. So great and sudden a change in the rate of growth occurred at no other time in more than 2000 years, although still greater extremes may have prevailed at certain periods before the time of Christ. The nature of the climatic conditions in the fourteenth century may be judged in part from the strands of Owens Lake, which lies only 50 miles from the Big Trees. The lake and its tributary river have been measured and analysed with great care by the engineers in charge of the Los Angeles aqueduct. As the lake has now no outlet all the salt carried into it must remain until precipitated. The amount of sodium and chlorine is such that there is little likelihood that any appreciable amount has been precipitated. Analyses of the water from two-thirds of the lake's drainage basin show that the accumulation of the present amount of chlorine would require 4200 years and of the sodium 3500 years, the average being 3850. Since this applies to only a little more than two-thirds of the basin, the number of years must be reduced to about 2000. The fact that a larger supply of water would bring more salines

than are now being poured into the lake obliges us to reduce the figure still farther. Therefore we conclude that at the time of Christ or later, Owens Lake must have overflowed and been fresh. The old outlet is plainly visible at a height of 180 to 190 feet above the present variable level. Large beaches and rock-cut bluffs show that the water stood long at this high level. The climate must have been correspondingly more moist than at present. Below the outlet strand at Owens Lake there are several others. These correspond closely with the fluctuations of the growth of the Big Trees. Therefore it is possible to date them. The beach of the fourteenth century is so peculiar that even the layman notices it. It is larger, more pebbly, and more distinct than those above or below it. Such a beach could only have been formed when the lake was swept by unusually strong winds.

Thus from places as far removed as California, Greenland, Norway, England, the Rhine and Danube country, the Caspian Sea and western China, we find evidence that the fourteenth century was a time when the winds were stronger, the storms more severe, the rainfall heavier, and the occasional droughts more severe than at present. If such conditions should be repeated in our day, it is quite certain that many of our engineering works would be put to a test which they could not stand. Dams and revetments would be washed out, towns would be inundated, and buildings would be wrecked by the wind. In the intervals between such disasters the storage capacity of our reservoirs might prove inadequate, for the droughts of the fourteenth century appear to have been as extreme as the storms. If this sort of thing could suddenly take place 600 years ago, there is no assurance that it may not come upon us today.

In order to avoid the disasters which may at any time suddenly arise through a return to the conditions of the fourteenth century two methods are possible. One is greatly to increase the margin of safety in all our engineering works. This would be prohibitively expensive in view of the fact that we have no assurance that such a period of climatic stress is likely to come upon us. The other method is to find out the causes of climatic variability, and to devise methods whereby we may predict the general character of the seasons for months in advance. If we could know that floods, droughts, or exceptionally low temperature were likely to afflict a certain region, it would be comparatively easy to make such preparations. The prediction of such events is at present totally

beyond our capacity, but that does not prove that it will continue to be so. It is only about forty years since we began to predict ordinary storms with any scientific accuracy.

The first step toward long range predictions of the weather is a full understanding of the causes of present variability. It is agreed on all sides that theoretically the most hopeful line of study is solar variations. Yet as Mr. Birkinbine has shown, the attempts to establish a correlation between terrestrial climate and changes in the sun have hitherto proved disappointing. Even this, however, as is well said by Professor Bigelow, is no ground for discouragement. It simply means that we are dealing with a big problem which is highly complex. In spite of seeming contradictions no phenomena have yet been discovered which are not in harmony with certain forms of the solar hypothesis. What follows is an outline of an hypothesis which has not yet been before scientists long enough to be tested. Even if it is wrong in certain respects, it shows that there are abundant possibilities which students have not yet considered.

Hitherto the chief obstacle to a solar hypothesis of climatic variations has been the unfounded idea that all parts of the earth ought to respond directly and in the same fashion to changes in the sun. That is, it has been assumed that if the sun grows warmer or cooler the whole of the earth's surface ought also to grow warmer or cooler. As a matter of fact it is now established beyond dispute that when the sun gives out an unusual amount of heat, the earth's *surface* is unusually cool, especially in equatorial latitudes. The word *surface* is emphasized because it is possible, and indeed probable, that when the surface is unusually cool certain higher layers may be unusually warm. Another fact is almost equally well established, namely that when solar radiation is active, cyclonic storms such as tropical hurricanes and the more gentle but widespread storms of our own latitudes are also unusually active. These two facts are closely connected, and the second seems to explain the first.

This brings us to our hypothesis. The sun appears to exert an influence upon terrestrial temperature in two ways; the first is direct, when the sun sends out more heat, the earth is warmed; the second is indirect, when the sun is more active the atmospheric circulation is altered and thus the distribution of temperature is changed. The indirect influence apparently may neutralize or even reverse the direct. The mechanism by which this result seems to be produced is as follows: one of the most characteristic features of all storms,

whether they be tornadoes, thunder storms, hurricanes, or the ordinary storms of temperate latitudes, is that in the center there is an upward movement of the air. The air may move rapidly or slowly, but in either case the lower air is carried aloft to a considerable distance. Almost invariably the air which moves upward is either absolutely warm or at least warm for the given season and latitude. Every one knows that the air grows warm before a storm in winter and that thunderstorms in summer are apt to occur when the air is especially hot. The rising of the warm air is accompanied by a movement of cold air so that the general surface temperature is lowered. At times of many sunspots the number and intensity of storms and the rapidity of the general atmospheric circulation increase. The result is that more warm air is carried upward. Thus the earth's *surface* is cooled, although the upper air may possibly be warmer than usual. This seems to account for the apparent contradiction between greater solar radiation and lower temperatures on the earth.

Another supposed obstacle to a solar hypothesis of climatic variations has been the well known fact that in the same latitude and in places only a few hundred miles apart variations of a contradictory nature are frequently observed. When these variations are plotted upon maps, however, it is found that they follow definite laws and are directly related to the solar cycles. For instance, at times of many sunspots the total storminess of the North American continent increases, but the central part of the United States experiences a pronounced decrease. This occurs regularly in each sunspot cycle. The increase of storminess takes place primarily in a pronounced belt extending through southern Canada and only covering a small part of the United States. Another belt of increased storminess passes through our southwestern states and across the Gulf of Mexico, where it is very faint, to the Atlantic Ocean where it strengthens and turns northeastward.

The exact boundaries of the areas of increased and decreased storminess at times of many sunspots vary from cycle to cycle, although the general location and shape of the areas remain nearly the same. For example, at times of solar activity a tongue of increased storminess projects southward from Canada into the United States. In general the tongue lies over Lake Michigan, but its position shifts from cycle to cycle. When the recorded level of Lake Michigan is plotted for fifty years or more we find that

nearly two-thirds of the time the level of the lake rises or falls in harmony with the number of spots, but at other times the two disagree. Formerly such a phenomenon was thought to militate against the solar hypothesis. Now we see that it is what would be expected. When the tongue lies over Lake Michigan, we find agreement, but when it shifts away there is disagreement. Our task is to find why and when it shifts away. The explanation probably lies in the fact that there are many kinds of solar variations, which produce diverse effects and which occur with different periodicities. For instance, prominences, faculae and magnetic variations as well as the visible changes in sunspots all seem to represent variations in the amount of solar energy sent to the earth. Each of these apparently influences the atmospheric circulation, and hence causes variations in the weather. Moreover a single type of solar activity may have several kinds of periodicity. Sunspots vary in cycles of about 3, 8, and 34 years as well as the well known 11 year cycle. None of the cycles, however, is permanent or regular. The 11 year cycle varies from 7 to 15 years in length, and suffers corresponding changes in intensity. Thus the climate of the earth appears to depend upon a complex series of solar changes which may combine to help or to hinder one another. To these must be added certain purely terrestrial phenomena, such as the presence of volcanic dust in the atmosphere, which also play a part in determining the temperature and movements of the atmosphere.

It is impossible here to explain the solar hypothesis more fully. It is done at length in a paper entitled "The Solar Hypothesis of Climatic Changes" in the *Bulletin of the Geological Society of America*, volume 25, 1914. The point to be emphasized here is that in spite of many and authoritative statements to the contrary, a growing body of climatologists are convinced that the variability of the earth's climate from year to year and from decade to decade is primarily due to variations in one or another of the several kinds of solar activity. If so, there is good ground for hope that we may discover how the changes take place and how to predict them. When that occurs the importance of the contribution of waterworks engineers to civilization will increase greatly. They will be responsible not merely for the construction and maintenance of all sorts of projects, but for interpreting the predictions into deeds, and thus actively forestalling the enormous damage which rises from variations in precipitation.

MR. CARL P. BIRKINBINE: Dr. Huntington's discussion is especially welcomed because his exhaustive investigations into past climatic changes permit him to add a record of one instance of a world wide interval of extreme precipitation and other climatic conditions, as well as mention several severe droughts in European countries. Some of these extremes mentioned have not been duplicated within the memory of any living person, probably the nearest approach being the unusually cold summer of 1816 along the north Atlantic coast, and also in some foreign countries. The full extent of this in the United States is not available because of the lack of records due to scanty population west of the Alleghenies, but not only in written records but also by word of mouth it has come down to us as "the year without a summer." Records of the general region in which Philadelphia is situated note that the winter months of this year were mild, and that the extreme unseasonable cold occurred in what we know as the hot months. The same region had, in 1915, a cool summer and therefore one marked by abnormal rainfall.

Dr. Huntington has noted an interval on the European continent when storms of unusual severity alternated with intense droughts, and some of the summers were so wet that reduction in crops, which we generally associate with deficiency in moisture, was produced by too much rain.

Included in the great disturbances of the fourteenth century was the violent tempest of January 15, 1362, which occurred in the midst of the great pestilence of London, the second pestilence. William Langland in *Vision of Piers Plowman*, Passus V, lines 13–15, wrote of it:

> He preved that thise pestilences were for pure synne,
> And the southwest wynde on saterday at evene
> Was pertliche for pure pryde and for no poynt elles.

and Fabyan says:

> In this xxxvii[1] yere, upon the daye of Seynt Mauryce, or the Xv daye of Januarii, blewe so excedynge a wynde that the lyke thereof was not seen many years passed. This began about evynsong tyme in the South, etc.

He states that it lasted for five days.

This storm is noticed again in Hardyng's Chronicles, and Blomefield relates that it blew down the spire of Norwich Cathedral.

[1] Referring to the reign of the sovereign.

Our climatic changes are a series of small cycles occurring within larger cycles, and these in turn within cycles of still greater magnitude, all being irregular in amplitude and period. Consequently we may expect that great extremes, which are produced by the most powerful causes, would cover enormous areas on the globe, while the small cycles may be confined to definite regions and greatly modified by local storm conditions and natural topography. It does not seem improbable to anticipate scientific progress which will give advance warning of the great and most unusual climatic conditions; and as engineering work is restricted to specific localities, we must use factors of safety which will forestall such damage as we are able to anticipate.

The solar hypothesis is the most satisfactory suggestion yet made of the causes of climatic changes, and when the studies of physicists and meteorologists can be based upon well coördinated and accurate data, frequently taken at a number of points, what now appear as discrepancies will be explained, and this complex problem at least brought to the point where additional research can follow a path more clearly outlined.

A MERCURY COLUMN ALARM FOR STANDPIPES

By W. E. Haseltine

Our company was for many years troubled greatly by having the standpipe pumped over. The standpipe is located in a residence district and its overflow caused a great deal of complaint among the residents and often threats of lawsuit, besides which it was annoying to the company for the reason that the water would freeze on and around the standpipe in cold weather. There were a number of reasons why this pumping over occurred.

First. The standpipe is located nearly a mile from the pumping station and out of sight from the same.

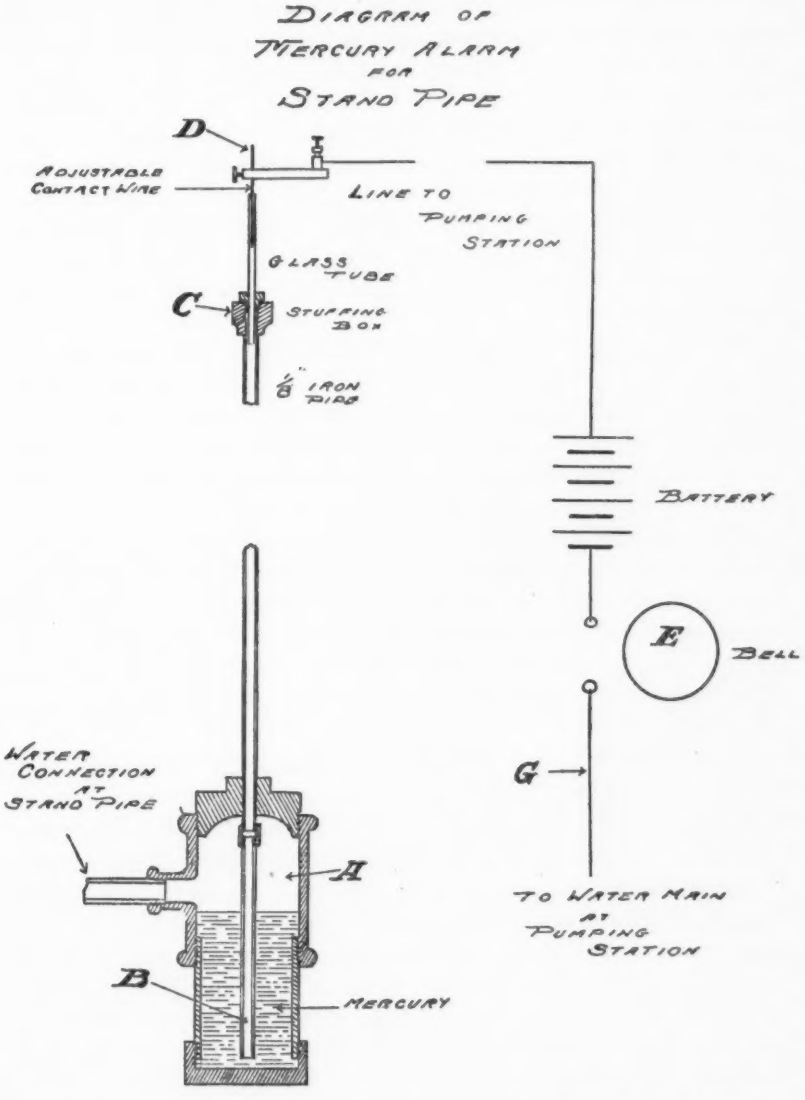
Second. The only means of telling when the standpipe was full was the pressure gauge at the pumping station, and the indications of this gauge would vary so greatly with the speed at which the pumps were running, the amount of water being used from the mains, etc., that it was not very reliable as an indicator, and unless the pumps were stopped at a point considerably below full standpipe we could never be sure that it would not run over.

Third. On account of the topography of our city, it was quite necessary to fill the standpipe almost to the top at every pumping to avoid an unnecessary amount of stopping and starting of the pumps and an increased pumping expense.

Many schemes were tried for correcting this condition, but with little success. A float making an electric contact was found impracticable on account of trouble with ice and excessive maintenance in other ways. A spring pressure gauge making an electric contact was also tried but, on account of the danger from freezing, this gauge had to be located in a damp valve pit underneath the standpipe, and the contacts consequently corroded and went out of business, and the gauge was also continually getting out of calibration.

The idea of a mercury column alarm then suggested itself, and after several attempts we succeeded in constructing one which has been in continuous service for almost nine years, and it has never failed to operate unless a wire to the pumping station has in some way been broken.

The accompanying drawing shows the general principle upon which this gauge is made and how it operates. A tap is made in the



pipe leading into the standpipe on the standpipe side of the valve controlling same, so that the gauge will never be subjected to excessive fire

pressures. This tap is connected by means of a regular corporation connection to the top of the mercury chamber *A*. Extending down into the mercury chamber is a small iron pipe *B* reaching nearly to the bottom, and this pipe extends vertically to a predetermined height, and about 6 inches of glass tubing is connected to the top thereof by means of a stuffing box *C*. This glass tubing is placed at such a height above the mercury chamber that at the time the standpipe is full the mercury column will stand at about the center of the glass tube. A metal contact *D* is arranged to slide up and down in this tube and this is connected to the wire leading to the pumping station, and the electrical circuit completed by the bell *E*, the set of batteries or bell ringing transformer *F* and the wire *G* attached to the water main at the station, this main making the return circuit.

The operation of the alarm is simplicity itself, the weight of the water column in the standpipe raises the column of mercury in proportion to its specific gravity until the mercury touches the contact *D*, when the bell rings at the station. The specific gravity of mercury being about 13.6, a 100 foot standpipe would require a mercury column something over 7 feet high.

This alarm has a number of advantages over any other that we are aware of. It is almost infallible, provided that the joints are made perfectly tight. It never has to be calibrated and is independent of barometer and practically of temperature. This latter is not strictly true, but we have found that the gauge operates perfectly at all temperatures that we get in this climate, from 100° above zero to 40° below.

The fact that 1 inch of mercury is practically equivalent to 1 foot of water makes it easy to set this gauge within one inch of water in the standpipe, which cannot be said of an alarm based on any other principle. The entire outfit can be made by any one at an expense not to exceed $20 to $25 outside of the line wire. About the only precaution which we would mention is: be sure to use an iron mercury chamber and iron pipe. Our ignorance of the fact that mercury would attack brass was the cause of much grief, and the loss of large quantities of mercury, but the final mercury chamber was made out of a short section of 2-inch pipe and a riser pipe out of ¼ inch ordinary black pipe.

EFFECT OF SOLUTIONS OF FILTER ALUM ON BRASS PIPE AND FITTINGS[1]

By G. R. Spalding

In 1906 the Hackensack Water Company installed a line of 2-inch standard seamless brass pipe to convey alum solution from the application tank to the dosing point, 170 feet distant. The line was made up with standard heavy pattern brass fittings and had a 2-inch connection through which water at 80 pounds pressure could be supplied for flushing purposes. The average rate of flow through this pipe was 7½ gallons per minute, corresponding to 43 linear feet per minute. Considerable trouble from plugging was experienced and as time went on it became necessary to flush the pipe more and more frequently. Leaks developed at the joints occasionally and sections of the line were removed, threads recut, new fittings supplied, and short pieces inserted to make up the length. This continued until October 1910, when it was found that the pipe was getting too thin to be rethreaded successfully and the line was removed and scrapped. At this time there was a hard yellow deposit in the pipe, uniformly ½ inch thick, which had cut down the available flow to less than 10 gallons per minute. During 1906 and 1907, 4 per cent solutions had been used much of the time, with periods when the strength had been increased to 6 per cent. During 1908, 1909 and 1910, 6 per cent solutions were the rule with occasional resort to 8 per cent strength. This 2-inch pipe weighed 48 pounds per length of 12 feet when installed in 1906 and 31 pounds per length when discarded in 1910.

Experience with this line made it evident that higher rate of flow was necessary to prevent plugging. Consequently a line of 1½-inch standard brass pipe with heavy pattern fittings was put in in October 1910. The experience with this line was much like that with its predecessor, except that there was little trouble with plugging. Occasionally leaks started at the joints, necessitating the removal of certain lengths, rethreading, inserting new fittings, etc., and

[1]Read at meeting of New York Section, December 15, 1915.

with attention of this nature the line lasted until May, 1914. When the pipe was scrapped it was found to be clean and bright inside, free from any deposit, and worn somewhat thinner on one side than on the other. This pipe weighed 36 pounds per length of 12 feet when installed in October, 1910, and 26 pounds per length when scrapped in May, 1914. During 1911 and 1912, 8 per cent solutions had been used most of the time, whereas from that date on to May 1914, 12 and 16 per cent solutions were in service. This line carried an average flow of $7\frac{1}{2}$ gallons per minute as had been the case with the earlier 2-inch line, so that the linear velocity in the $1\frac{1}{2}$-inch line was 71 feet per minute.

In May, 1914, the first $1\frac{1}{2}$-inch line was supplanted by a new one of brass, similar in essential detail. This line gave no trouble from leaks until April, 1915, when it suddenly showed signs of going to pieces generally, and examination disclosed the fact that the pipe had lost 6 pounds per length in less than a year. This line had been conveying 16 and 20 per cent solutions ranging in temperature from 70 to 80° F. during the winter months. This increased temperature was occasioned by preheating the water to facilitate preparation of solutions. The rate of flow was materially the same as in previous years.

It became evident that brass was not going to handle these solutions of increased strength, and consequently, in April 1915, a new $1\frac{1}{2}$-inch line of commercial copper tube with special copper fittings of heavy pattern was installed. Experience with the previous line made it clear that the trouble with ordinary brass pipe was not so much in its tendency to corrosion in general as in its specific inability to stand up at the joints. Consideration of a typical threaded joint in which much of the metal is cut away to form the threads, shows that the whole line is no more permanent than this weakest point. It is helping matters but little to increase the thickness of the pipe and fittings. To overcome this difficulty what is known as the slipjoint fitting was adopted and still another line of $1\frac{1}{2}$-inch pipe installed, in this case of commercial bronze, made up with these special fittings. These were made according to the writer's specifications. This line was put in in May 1915, and the bronze pipe showed a loss of $2\frac{1}{2}$ pounds per length of 12 feet on November 13, after six months' service. The copper pipe showed a loss of only $\frac{1}{2}$ pound per length of 12 feet in seven months of service. With these slipjoint fittings a line of pipe can be made up with ex-

treme ease and rapidity; a section may be removed anywhere without disturbing the rest of the line, and the labor involved is slight. These factors are of great value in a filter plant where interruptions to the service are serious. Moreover, it should be possible to use with these fittings pipe which has become much too thin to admit of the ordinary threading process, and thereby effect a material saving.

Pipe made up with these fittings must be properly supported and if it is to carry any considerable pressure care must be used to anchor the line properly. These and other details, however, are matters peculiar to each installation and do not detract from the fundamental purpose for which the fittings have been adopted, namely to dispense with the threaded joint.

Summarizing the experiences with brass pipe and fittings:

First. Ordinary brass pipe and heavy pattern fittings may be expected to give several years' service conveying alum solutions of 8 per cent strength or less.

Second. Threaded pipe will give more or less trouble from leaks at the joints and will have to be taken down and rethreaded at least once during the possible life of the pipe. Slipjoint fittings present distinct advantages over ordinary threaded ones because of the above consideration.

Third. For conveying alum solutions of more than 8 per cent strength brass is not suitable.

Fourth. Increasing the temperature of alum solution greatly increases its solvent action on brass.

Fifth. The presence of iron in certain forms in filter alum seems to increase its corrosive action upon brass to a marked degree. In support of this statement the writer will relate the details of a rather disastrous experience:

In April 1914, a carload of special iron and aluminum sulphate was received to try out on a practical scale. It was stated to contain about 2 per cent of iron in the ferric form in addition to the ordinary 17 per cent of alumina, and should, therefore, be much more potent as a coagulant. It was made up in 16 per cent strength as customary and the test started. After thirty-two hours a 1½-inch gate valve on the application tank started to leak badly. It was replaced with a new one and as the valve had been in service some time no particular attention was paid to the incident. Twenty hours later alum solution started to squirt through the bonnet of the new valve and the test was summarily finished. After taking

account of the damage done it was found necessary to practically rebuild the alum piping system, and the next month, May 1914, the new line of 1½ inch brass already spoken of was put in. The 1½ inch gate valve that was completely ruined in twenty hours would have lasted from two to four months with ordinary filter alum.

CLEANING THE BAYSIDE FILTERS[1]

By E. G. Manahan

The writer has been asked to say a few words regarding the methods used in cleaning the Bayside filters. The notice of this meeting states, however, that "filter troubles" are to be discussed. Bayside filters and troubles have at times been considered to be nearly synonymous terms; but in looking back over these troubles they seem to have been largely the result of too great expectations. However, such troubles as were had led to a study and comparison of methods of cleaning which may be of some interest.

The Bayside filters are small, slow sand filters, belonging to the Department of Water Supply, Gas and Electricity of the city of New York, and are located in the Borough of Queens, about 15 miles from the city hall. They furnish between one and two million gallons daily, and were put in service in the summer of 1911. During the writer's brief stay with that department, they came under his observation, and to some extent under his control.

The filters are five in number, and together have an area of about one-third of an acre. They are not covered, but are formed by dividing a long concrete lined basin having sloping sides into five parts by means of concrete cross walls. They differ from most filters in that they were designed to be cleaned by the Brooklyn method. This method, as is well known, consists in drawing the water on the bed down to within an inch of the sand, and then causing water to flow across the bed from one end to the other while the sand is being raked by men standing on the surface. Since by this method removal of the sand from the bed for cleaning is not required, the depth of sand provided in these filters is only 26 inches, instead of the more customary 4 feet. For admitting the wash water and taking it away, there are channels along the inlet and outlet ends of the filters, cut into the sloping sides of the basin with their tops at the elevation of the sand line. Wooden partitions, driven into the sand, extend longitudinally over the beds between these channels, dividing the

[1]Read at meeting of New York Section, December 15, 1915.

filter surface into bays about 11 feet wide, and of the length of the bed. By blocking off the other bays, one bay at a time may be cleaned.

It was intended that the filters should be operated at relatively high rates, and therefore the sand is as coarse as could be obtained without unduly increasing its cost. It has an effective size of about 0.35 mm., and a uniformity coefficient of about 2.1. The filters are provided with loss of head gauges and rate controllers, thus obviating attendance at night. In other respects than those mentioned above the filters are in accord with generally established practice.

The water supply is taken by gravity from Oakland Lake, nearby. This lake is fed largely from underground sources, although considerable surface wash reaches it from adjacent steep slopes. The water is therefore ordinarily of good character, and the turbidity low, averaging about 6 parts per million, and seldom exceeding 12. Except during the first summer, no serious trouble has been experienced from microörganisms, although these are at times numerous and copper sulphate has been used to a slight extent in certain parts of the lake. The bacteria run low, averaging perhaps 100; and B. coli, though generally found in 10 cc. samples, is generally absent in 1 cc. Purification is reasonably satisfactory, though not always so when the filters become very dirty. Turbidity and microörganisms are generally entirely removed, and bacteria and B. coli are substantially reduced.

In the spring of 1912, when the filters had been in service more than half a year, the writer was directed by Mr. I. M. deVarona, then chief engineer, to study, in conjunction with Mr. John A. Byrne, then borough engineer of Queens, the question of cleaning the filters so as to get as high a yield as possible. Because of early troubles from microörganisms or for some other reason, the filters had generally been cleaned up to that time by scraping the sand surface and piling the scraped material on the banks. They had been giving reasonably satisfactory yields during the winter; but in the spring it was found impossible after a time to run them for more than a few days between successive cleanings, either by scraping or by the Brooklyn method.

The filters had been running at a rate of filtration of 350,000 gallons each daily, or about 5,000,000 gallons daily, and it was desired to increase this rate. When the filters were designed, it was apparently expected that, with the Brooklyn method, which is rapid

and requires less than a day's time, and with water of very low turbidity, rates perhaps as high as 10,000,000 gallons daily might be maintained.

In the spring of 1912, it was very difficult, with the Brooklyn method, to maintain the 5,000,000 gallon rate. It was thought that the hard crust which was found to form just below the depth reached by the garden rakes used might be responsible for the difficulty, and this was doubtless true to a certain extent. In order to break up this crust, clam rakes, having teeth about 6 inches long, were employed. Handling these rakes was slow, hard work, and the gain was not commensurate. Turning over the sand to a depth of 8 or 10 inches by spading helped considerably, but this was even slower than the use of clam rakes.

The trouble was probably due as much if not more to insufficient cleaning of the sand by the Brooklyn method, since less difficulty was experienced when the beds were cleaned by scraping instead of the Brooklyn method. But on account of lack of proper facilities for washing sand, it could not be replaced, and the continual removal without replacement was objectionable, not only because the original depth of the sand was small, but because lowering the sand level meant increasing the depth of water flowing over the sand while cleaning by the Brooklyn method, thus reducing the velocity of the wash water and interfering materially with its efficiency.

While we were struggling with this state of affairs the situation was somewhat relieved by an apparent improvement in the quality of the raw water. It has since then always been noticed that, during the summer, and particularly during the winter, the runs between cleanings have been comparatively long, while during the fall and especially during the spring, the runs have been comparatively short. No conclusive cause for this is found by inspecting the analyses of the raw water, but it may be due to the character of the amorphous matter stirred up by the overturning of the lake, though the lake in many parts is not very deep.

Since it was necessary to have a sand washer of some kind anyway, and since the use of a machine would enable the immediate replacement of the sand, a sand washer and an ejector hopper for handling the sand were purchased. Also, two other methods of cleaning were attempted, with a view to improvement over the Brooklyn method.

One, suggested by the then division engineer, Mr. T. C. Atwood,

was called the "jet" method. After first removing the heaviest of the deposit on the sand by going over the bed once with the back of the rake, as in the Brooklyn method, then, instead of proceeding to go over the bed again, using the teeth of the rake, which is the final process in the Brooklyn method, the operator, standing upon the surface of the bed over which the wash water is flowing, directs a stream of water from a hose nozzle down into the sand. Such a jet appears to soften and cleanse the sand quite well. The operator can tell by the feeling of the sand beneath his feet whether it has been washed or not, as he will sink in where it has been washed.

Another method, suggested by Deputy Chief Engineer Brush, was called the "water rake" method. The apparatus used is in the form of a rake, with handle, head and teeth of wrought-iron pipe. The teeth are about 4 or 5 inches long, closed at the ends, and perforated with $\frac{1}{8}$ inch holes. A curved sheetiron plate or shoe, placed under the head, serves to support the rake when placed on the sand. Water under pressure introduced through a hose connected at the upper end of the handle is discharged in numerous jets under the sand surface, and as the rake is moved along by the operator, this water cleanses the sand and is carried away by a stream of water passed over the bed as in the Brooklyn method. Previously to using the water rake, the heaviest part of the surface deposit is usually removed with the back of the garden rake, as described under the jet method. The results attained by the use of the water rake, both in cleansing and in softening the sand, are reasonably satisfactory.

It was later determined to make comparative tests as to the economy of the four available methods of cleaning, by using each method exclusively upon a single bed. In carrying out the tests, as is frequently the case, some irregularities occurred, and hence the writer will not attempt to give definite figures. A brief statement regarding the results may, however, be of interest. It is not claimed, of course, that these results are applicable necessarily to other filters or to other waters.

It was quickly found to be entirely impracticable to use the Brooklyn method alone continuously, as the length of runs gradually became very short. Therefore, the sand washing machine was used once or twice after four or five cleanings by the Brooklyn method. The cleaning of this filter was carried out in a more irregular manner than that of any of the others, and this filter appeared to show the highest cost and the lowest yield.

The attempt to use the water rake was soon abandoned. Figures for the first runs made seemed to show that it was unduly expensive, although this was later shown to be untrue. The rake, as designed, was difficult to operate, because, when the operator kept it moving slowly enough to allow the sand to become softened, he had great difficulty in keeping the rake from sinking into the sand. Also, on account of lack of facilities for turning off the water at the rake, the jets made the work disagreeable to the operator whenever the rake was removed from the water, especially during cold weather. The handling of the long line of hose behind the rake also involved considerable labor. The writer believes that it would have been possible to have designed a rake which would have done work superior to that accomplished by the Brooklyn method, and that would not have sunk into the sand; but believes that such a rake would not have any advantage over the simpler jet method.

The jet method is probably cheaper than any of the others. The operators like it fully as well as the Brooklyn method, as the hard work is done by the jet of water, and the operator merely holds the nozzle and moves the hose, which is easier than using the teeth of the garden rake. The bed has to be out of service somewhat longer than with the Brooklyn method, unless more than one jet of water is available. An apparent objection is that care has to be used to be sure that all parts of the bed have been uniformly subjected to the action of the jet, although there is no evidence of any trouble from such a source. The method can be used to soften the sand to any desired depth, and might well be used, in the writer's opinion, in place of the customary deep scraping, as the sand is well washed in place.

As to the continuous use of scraping and the sand washing machine, compared with the use of the Brooklyn method aided by the machine when necessary, the continuous use of the machine appears to be cheaper. The men like it better, as they can keep dry and there are no troubles from leaky boots. The sand washing machine alone is cheaper whenever long runs are desirable, as in the winter, and also when the water is particularly foul. The combination of the two methods is probably cheaper when the water is in good condition, as in the summer, if microörganisms are not abundant.

The tests were made with a rate of filtration in all cases of approximately 5,000,000 gallons daily, but there has been no particular

difficulty with the comparatively large force of men available for cleaning purposes, in maintaining, by either the sand washing machine method, the machine and Brooklyn methods combined or by the jet method a rate of 7,000,000 gallons daily, which is more than the capacity of the water shed of the lake in dry periods.

For obtaining the greatest total yield at the least cost, it appears to the writer that a combination of methods which was not tested is best; that is, a combination of the jet method and the sand washing machine. The jet method cleans the sand to a considerable depth, and keeps it soft; while the use of the sand washing machine keeps the surface layer clean, and, especially at times when there are large quantities of organic matter present in the raw water, does more thorough work in the upper layer than the jet can accomplish. By the use of the jet deep scrapings can be avoided, for the discoloration of the sand extends very little below 2 inches; and it is the deep scrapings that add materially to the cost of the sand washing machine method at Bayside, especially as the foreman seems to be tempted, whenever men are available and the demand for water not pressing, to scrape as deep as the time permits.

At Bayside, as generally elsewhere, the Brooklyn method has an advantage in point of cost, in that the wash water is raw water which has not been pumped, while with any of the other methods described it is necessary to use pumped filtered water for washing. This advantage, however, does not, in the writer's opinion, make the cost of the Brooklyn method as low as that of the jet method.

FILTER OPERATION[1]

By S. M. Van Loan and Albert Tolson

Conditions governing the operation of filters are not changing to any marked extent as time passes, but the methods adopted to cope with situations have naturally been in a progressive stage. Each year teaches a filter operator a lesson, and a season should not pass wherein some economy or some improvement could not be suggested.

The tendency of health commissions to protect watersheds from harmful influences which may bear directly or indirectly upon the content of rivers supplying water to our purification works, has given much encouragement to water works officials, and with the advance of improvement in the raw supply, the load on each filter plant is reduced.

Popular demand centers upon a clear water service and adverse comment seldom manifests itself when a water works furnishes a sparkling supply throughout its distribution system. Few residents of a large community have any conception of the appearance or harmful content of unfiltered water, and a filter superintendent must have his plant in such a state of preparedness that it may cope with one load or several should there be a repetition of unusual conditions during a short period of time.

As water passes to a distribution system, the task of determining the quality is imposed upon the laboratories. The registering of results in a speedy way gives the plant operator evidence to correct many troubles that might assume serious proportions should warnings be neglected. The analysis of raw waters is valuable more as a matter of record than as an influence in operation.

At the Delaware unit, Torresdale, the raw water has been applied without treatment or sedimentation. Upon occasions when the elements of wind, tide and temperature have entered, the supply of water from the pumping station has been below the demand of the plant. The water on the sand surface decreases in depth and

[1]Read at meeting of New York Section, December 15, 1915.

all filters with a high loss of head automatically decrease in rate. In order to keep the plant in operation these filters are washed, the greater the loss of water on the sand the more frequent the washing, resulting in an increased amount of wash water and power. High winds frequently create waves which scour the river banks causing increased turbidity and the natural sequence is shorter runs and more frequent washings.

At the time of writing, a basin which will admit of 12 hours' sedimentation is under construction, and with the application of a coagulant it is expected to materially reduce turbidities and bacteria in the water applied to the preliminary filters.

These filters are of a rapid sand type operating at an 80 mg. rate through 30 inches of graded gravel and 12 inches of 0.8 to 1.0 mm. sand. Air and water for washing are admitted through a $\frac{3}{16}$-inch orifice on under side of pipe so spaced that each wash influence must control 33.1 square inches.

Observations to determine the depth of sand on the prefilters have been taken at various times and after a three year period of operation it was noticed that from 1 to 3 inches of sand had been lost and subsequent inspections indicated there had been a reduction of sand depth at the rate of 1 inch per year. The greater proportion of this loss was due to the escape with mud removed during washing, and the remaining loss has been carried down through the gravel into the under drains finally lodging in the controllers. Many of the $\frac{3}{16}$-inch orifices are closed with rust or dirt and the lateral piping is becoming choked with barnacles. The cast iron manifolds were not tapped, in consequence of which the sand and gravel immediately above receive no influence from air or wash water. As a result this sand becomes so charged with mud that it has been found necessary at times to remove it with shovels and replace with clean sand. Caps are placed on the ends of the lateral piping forming dead ends where rust and other matter accumulate, clogging the holes near the extremities. As the capped ends of these pipes are spaced 3 inches from those of the adjacent series the volume of unwashed sand and gravel above will gradually increase until a considerable area of sand throughout the filter gives no service.

Experiments to determine the efficiency of different sand depths upon these preliminary filters have been conducted for several years and then contrasted with the percentage removed by the entire set of beds. These records show 49, 84 and 68 per cent efficiency

respectively for a 3-inch depth, an 18-inch depth and the average depth of 9 inches over the combined area. From the results obtained by these experiments it was decided to increase the depth of sand to 18 inches on all the preliminary filters at this station. A contract has been let for a sufficient quantity of sand to furnish each filter with a depth of 17 inches. Before placing it will be necessary to raise the wash water troughs and gullet 6 inches, which work is now being done.

The demand for water from the Torresdale plant requires an average rate through the final filters of about 4,500,000 gallons per acre, and the present year has given the plant its heaviest load, as the dredging for the new basin has forced a heavily charged water upon the prefilters which unit has not, on account of sand deficiency as described above, performed efficiently. Deep cleaning of final filters is routine work at this plant and a "house-cleaning" is necessary at least every two years, at which time a layer of sand just sufficient to protect the gravel is left undisturbed.

Schuylkill water at Philadelphia readily yields to filter purification. After a severe local storm a water charged with a heavy yellow, suspended matter is encountered. This soon clarifies itself and has very little effect upon the filters. A severe general storm produces first a heavy, red water, followed closely by one charged with coal dirt from the mining regions, which water is hard to clear, at times carrying a very disagreeable gaseous odor and taste. Aeration and sedimentation reduce the gas, but when the water is heavily charged much passes through the filters and carries to the house spigot. Naturally many complaints from the consumers are registered and all sorts of alleged disorders from its effects are reported.

The Schuylkill units are provided with sedimentation basins and have, in addition, the aid of a coagulant at times of heavy turbidities. This river rises rapidly after a heavy storm and it is upon the slow or rapid rise and extent of the storm that the superintendent decides whether to start dosing. A high turbidity of short duration will require no coagulant, while one much lower covering an extended period of time will necessitate its use.

At Queen Lane the preliminary filters are of the same type as those at Torresdale. The wash water is applied through $\frac{3}{4}$-inch brass strainers 3 inches long containing $\frac{3}{16}$-inch holes discharging horizontally from the top. These strainers are inserted in slabs

of reinforced concrete at 9-inch centers above the main and lateral collectors. Around and above these strainers is placed 15 inches of graded gravel and 12 inches of 0.8 to 1.0 mm. sand. The air is applied through 1-inch brass piping between the second and third layer of gravel or about 23 inches below the normal sand surface. This piping is tapped on the under side with $\frac{1}{8}$-inch holes spaced 6 inches apart and the pipe is set on 9-inch centers making an area of 54 square inches under the control of each orifice. Air and water can be used jointly or separately. After three years of service an increased depth of sand was observed in the beds. Further inspection developed the fact that the sand and gravel were abnormally charged with mud at such points in the filter not well under the control of the washing influence. No sand of any quantity has been lost and on the contrary this increased depth was recorded. These filters were developing a 70 per cent efficiency but the presence of large cracks upon the sand surface after a washing led to the thought that the sand character was changing.

The low rate demanded from this filter allowed too extended a run and when the loss of head on the bed indicated the end of a run, a filter highly charged with mud was presented. The regular wash was considered sufficient to clean for another long run. This rise in the sand surface showed an apparent depth of 16 inches of sand where only 12 inches had been placed.

Experiments were made to wash the filters more frequently, also to combine the air and water in washing. Neither cleaned sufficiently, and finally it was decided to spade the sand to a depth of about 12 inches with coke forks, following with a raking of the surface and then washing in the ordinary manner. The filters at this station operate at about a 50,000,000 gallon rate and run about five or six days between washings, a 4.5 foot loss of head marking the limit of run. The more frequent cleanings have now been resorted to, one-third of the plant being washed each day, giving each filter a three-day run with a maximum loss of head of about two feet. This method is very slowly but surely improving the situation. The application of the air and wasb water at the same time is hardly feasible as it forced the $\frac{1}{8}$-inch gravel into the sand and caused considerable loss of sand in the wash water troughs and gullet. The spading of the sand has broken up the mud and has been the means of eliminating a number of the cracks.

Considerable trouble has been experienced with the sticking of

rate controllers at Torresdale. This is caused by the presence of sand grains between the side of the piston and the piston chamber. Efforts have been made to keep the controllers working freely by turning them several times daily with hand wheels, but as an unreliable human element enters at this point, it proved unsuccessful. These pistons are now being removed and turned down $\frac{1}{16}$ inch, decreasing their diameter. This permits the sand drains to pass and prevents the piston from sticking in one position. At the present time all the controllers so treated are working satisfactorily.

The Philadelphia filters are located at a considerable distance from the residence section of the city, and often, during times of bad travel, the work of operating filters is seriously interfered with by shortage of labor. At times this shortage is overcome by working additional hours, but, as city labor receives one and a half time or double time for such work, economy of operation does not result.

Constant attention to the depth and condition of the filtering materials is most important. Thorough inspection of each filter unit should be a matter of routine work. Upon one occasion after a long period of dry weather, a storm produced a heavily charged river, the final filters at one of the stations went out of service rapidly and after being cleaned, short runs ensued. Inspection showed subsurface clogging of the sand. The lower 2 to 5 inches of sand above the gravel was compact and dirty, above which was found a layer of clean sand and in order layers of clean and dirty sand alternated every few inches until the sand surface was reached.

In order to remove the subsurface layers the entire body of sand extending to the gravel was washed. This is the third time it has been found necessary to wash the full depth of sand in the filters at this plant. This subsurface clogging is caused by placing clean sand upon the old unwashed content. The undisturbed sand appears clean but the voids are partly filled with the gelatinous matter removed from the water in past runs, and, as the unwashed sand is more compact, due to this foreign matter and also to the workmen walking upon it, it offers greater resistance to the water passing through than the newly washed sand above. The suspended matter passing through the upper layer of the clean, loose grains will be caught and retained by the more compact layer beneath. When this under layer becomes too dirty to permit the desired quantity of water passing, a deeper scraping is needed to give it life.

Sometimes during periods of low turbidity a superintendent finds his filters of the slow sand type producing long runs, the loss of head increasing slowly or at times decreasing. With a sudden rise in turbidity of the applied water the loss of head leaps and the plant's capacity is so reduced that every means is adopted to supply the demand for water. One experience of this kind will be sufficient to teach a superintendent to keep enough units of his plant in condition to meet any and all requirements.

In washing the sand in slow sand filters by separating and ejecting methods a quantity is carried off by the wash water and is retained in bins erected on the courts of the plant. A large percentage of this sand is too fine to be replaced in the beds, and an effort has been made to separate it from the sand of desirable size. These efforts have not been entirely successful and when the sand is removed from the courts and placed in a filter, short runs will ensue until a turning over is accomplished by a subsequent cleaning. The undesirable fine sand on the courts is removed from the plant and discarded.

Deep cleanings of slow sand filters should be avoided as much as possible in the winter months. Experience has proven that a filter will give much better service when the sand is washed before cold weather sets in than it will when washed deeply in the winter.

Chlorine apparatus is attached to each plant and a low degree of dosing ($\frac{1}{2}$ pound per million gallons) is applied upon the Schuylkill plants throughout the greater portion of the year. At times when general rains have scoured the water shed contributing to the respective rivers, a heavier dosing is applied more particularly as a precautionary measure. The maximum quantity used at the Schuylkill plant is one pound of chlorine per million gallons of water. On account of the disturbance of dredges the dosing at Torresdale has been at the rate of $1\frac{3}{4}$ pounds per million gallons.

The point of chlorine application at all stations is at the inlet gate house of the filtered water basins. No extra labor is required for this service and the character of water at remote locations in the distribution system, many miles from the filter plant, is highly satisfactory bearing the endorsement of the state and city health departments.

IRON REMOVAL BY RAPID SAND FILTRATION[1]

By Frank E. Hale

Upon the Brooklyn watershed there are two mechanical filter plants originally designed to purify by alum treatment the waters of Baiseley's Pond and Springfield Pond. A few years ago the operation of both of these plants was changed to that of iron removal from well waters at these points. The following table (No. 1) shows the character of the water treated at the Baiseley plant together with its efficiency in iron removal:

TABLE 1

Baiseley's filter plant

	1912		1913	
	Raw water	Filtered water	Raw water	Filtered water
Chemical analysis, parts per million:				
Nitrogen as Free ammonia	0.429	0.111	0.500	0.211
Nitrogen as Albuminoid ammonia	0.045	0.016	0.034	0.026
Nitrogen as Nitrite	0.002	0.025	0.012	0.009
Nitrogen as Nitrate	1.18	0.98	1.05	0.87
Chlorine	12.5	12.7	11.0	10.8
Total solids	162.	134.	160.	143.
Hardness	62.	66.	62.	70.
Alkalinity	37.	38.	41.	34.
Iron Average	10.72	0.47	11.35	0.32
Iron Minimum	7.60	0.25	6.00	0.10
Iron Maximum	14.60	0.75	26.00	1.00
Biological examination:				
Bacteria per cubic centimeter	2	1	2	1
B. coli 0.1 cc	0%	0%	0%	0%
B. coli 1.0 cc	0%	0%	0%	4%
B. coli 10.0 cc	0%	0%	2%	9%
Microscopic organisms, units per cubic centimeter	0	0	0	0

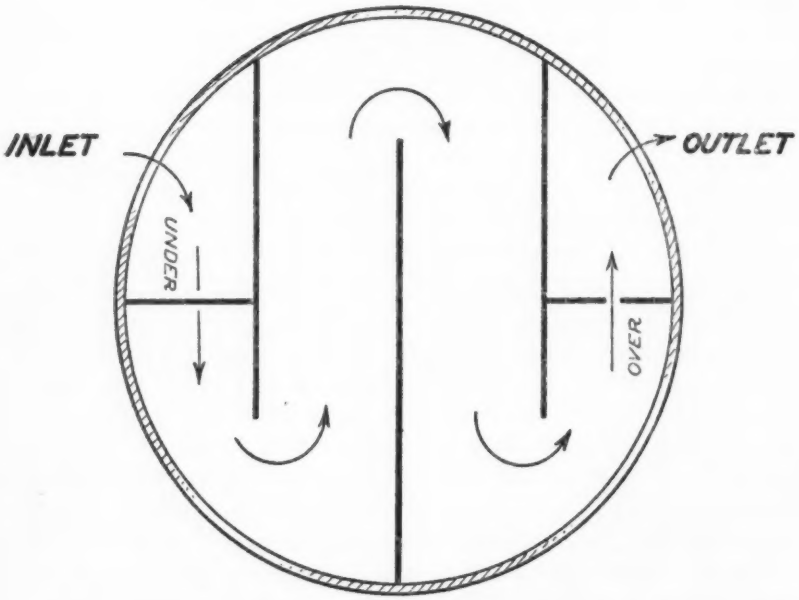
It will be noted in the above analyses that there is a reduction not only in iron but in the nitrogen determinations and total solids.

[1] Read at meeting of New York Section, December 15, 1915.

Without quoting analyses the results at the Springfield plant have been equally satisfactory although the character of the water is entirely different, being a mixture of two waters. The water is less hard, has considerably more chlorine and only a few parts of alkalinity.

It is not necessary to describe both plants but it may be well to give some details of the operation of the Baiseley plant. There are ten

SEDIMENTATION BASIN,
BAISELEY'S FILTER PLANT



filter tanks 15 feet 3 inches in diameter, arranged in two rows, with two sedimentation tanks 18 feet in diameter, one for each row of filters. The sedimentation tanks are baffled as shown in diagram 1.

The water is pumped and boils up into the inlet chamber, passes *under* the first baffle, back and forth around the center baffles and *over* the last baffle into the outlet chamber. The only aeration is due to a leakage of air in the well system to the extent of about 5 per cent by volume, and absorption of oxygen from the air during

sedimentation and filtration. The water passes the sedimentation tanks in about thirty-five minutes. It enters the filters through baffle chambers at the bottom, rises to the top of the sand beds and passes down through 2 feet of sand, 6 inches of fine gravel and 6 inches of coarse gravel to the strainer system. The filters operate at about 100,000,000 gallons per acre per day.

The sand originally in the filters had an effective size of about 0.37 mm. but had become coarsened by removal of fine sand during washing to about 0.48 mm. when the plant was started for iron removal March 21, 1912. During the first year of operation the sand changed still further to an effective size of 0.65 mm. with a uniformity coefficient of about 1.6. The depth of sand decreased from 30 inches to 18 to 28 inches in different filters.

The sand is washed by reversed flow of filtered water, together with agitation by compressed air, and assisted by raking or paddling by hand. Wash water amounted to about 5 per cent of the yield in July, 1913, and is about 2 per cent now; rate of washing 725 gallons per minute for thirteen minutes. The period of run, at first forty hours, was soon shortened to twenty-four hours, was about sixteen hours in a year's time and now is about fifteen hours. The filters are washed at 8-foot loss of head.

The sand becomes coated with iron oxide and thus ripens, this oxide acting to oxidize the iron in the water probably according to the equation:

$$FeCO_3.H_2CO_3 + Fe_2O_3 + H_2O = Fe_3O_4 + 2\,H_2CO_3$$

The sand filters thus become not only filters but oxidizing contact beds. At the start the iron was not efficiently removed but improved rapidly as the sand ripened. In four months after operation started the iron was down to about 0.5 p.p.m.

In the summer of 1914, the department of health ordered the Queens County Water Company to shut down their station at Rockaway Park owing to high iron content and resulting complaints from consumers. As the water was needed, the Department of Water Supply, Gas and Electricity coöperated with the water company in designing a rapid sand filter in accordance with the experience at Baiseley and Springfield Stations. Owing to the necessity for rapid construction certain difficulties were encountered, and the studies made to bring this plant to a high state of efficiency seemed worthy of record. The first conference was held July 31, 1914. Construc-

tion was started August 3, one filter completed August 18, the second completed August 19, and both put into service August 21, there being thirteen working days with two days' loss on account of weather.

The morning after the conference a sample of the water to be treated was brought to Mount Prospect Laboratory for experiment. Table 2 shows the analysis and results of experiments made to remove the iron:

TABLE 2

Analysis of well water—Rockaway Park Station

	p. p. m.
Free carbonic acid (CO_2)	31.2
Iron (Fe)	11.20
Hardness ($CaCO_3$)	47.
Alkalinity ($CaCO_3$)	32.
Chlorine (Cl)	64.0
Nitrate (N)	0.0

Laboratory experiments

	p. p. m.
Iron after aeration for one-half hour and filtered through paper	7.20
Iron after neutralization of carbonic acid with soda ash (Na_2CO_3) and filtration through paper	0.30
Iron after neutralization of carbonic acid with calcium hydrate (CaO_2H_2) and filtration through paper	0.10

The experiments indicated that if simple aeration did not sufficiently remove the iron the addition of either soda ash or milk of lime to take up the free and halfbound carbonic acid would render filtration effective. The plant was designed so that chemicals could be used. Aeration was accomplished by pumping the water vertically into the air, allowing it to splash into a trough and pour over a weir as it passed through a small sedimentation tank. The filters were built in duplicate, of heavy plank, in rectangular shape. The water came onto the sand from a central trough and the filters were arranged to wash by reversed flow into a central trough. The wash water passed to a hole dug in the sand.

Many samples of sand were analyzed, but owing to shortness of time the attempt was made to procure sand of right size on the spot by screening, since the first sample from the bank had an effective size of 0.51 mm. and a uniformity coefficient of 3.0. This was an unwise procedure. Table 3 gives results of analyses after the first season's run.

TABLE 3

Analyses of sand samples from filters after first season

SAMPLE NO.	DATE EXAMINED 1914	SOURCE	EFFECTIVE SIZE	UNIFORMITY COEFFICIENT
1618	October 13	Filter 1, top sand ½ inch–¾ inch thick	0.28	1.5
1619	October 13	Filter 1, just below top sand	0.84	2.2
1620	October 13	Filter 1, 1 foot depth	0.95	2.1
1621	October 13	Filter 1, bottom sand on screens	0.62	3.1
1622	October 13	Filter 2, top sand	0.27	1.5
1623	October 13	Filter 2, just below top sand	0.48	2.1
1624	October 13	Filter 2, 6-inch depth	0.94	2.0

It will be noticed that the top sand was altogether too fine and the bulk of the sand too coarse.

During the first season several inspection trips were made to the plant and many experimental tests carried out. Table 4 gives the results obtained on September 16, 1914:

TABLE 4

Experimental tests during inspection made September 16, 1915, Rockaway Park

HOUR	SAMPLE	RATE OF FILTRATION		SODA USED PER DAY	CARBONIC ACID CO_2	IRON Fe
		Gallons per minute	m. g. a. d.			
				lbs.	*p. p. m.*	*p. p. m.*
8.45 a.m.	Raw water	325	57	700		12.0
8.45 a.m.	Filtered water	325	57	700		0.3
11.20 a.m.	Filtered water	640	112	700		1.7
12.40 p.m.	Filtered water	600	105	0*		1.4
1.30 p.m.	Filtered water	600	105	0	22.0	3.4
1.40 p.m.	Filtered water	380	66	0		2.5
2.30 p.m.	Filtered water	380	66	0	27.0	3.0
3.00 p.m.	Filtered water	380	66	0	28.0	2.2

* Stopped 30 minutes previous.

During the early part of the season soda ash was used to neutralize the free carbonic acid, but the removal of iron was not satisfactory, there being nearly 2 p.p.m. of iron left in the filtered water when running at the rate of 112,000,000 gallons per acre per day, at which rate the plant should have run efficiently in order to equal the results obtained at the city's filter plants. It will be noted in the table that when running at 57,000,000 gallons per acre per day,

the iron in the filtered water was only 0.3 p.p.m. but at the higher rate was 1.7 p.p.m.

The floc produced by soda ash is very fine and somewhat colloidal in character, and as the city's plants obtained perfect results without the use of any coagulant, it was believed that this was a useless expense and that the plant would work as well, if not better, without the soda ash, although the latter apparently precipitates the iron quicker. Maintaining the high rate, the soda ash was cut out and the analysis made at 12.40 p.m. showed as good results. The results were not quite as good an hour later, the iron having in-

TABLE 5

Filtration without soda at Rockaway Park—October 2, 1914

SAMPLE	TIME	RATE OF FILTRATION	CARBONIC ACID* CO_2	IRON* Fe
		m. g. a. d.	*p. p. m.*	*p. p. m.*
Raw water	3.45 p.m.	72.5	40	10.4
Filtered water	9.45 a.m.	61.5	12	1.0
Filtered water	10.15 a.m.	67.0		1.6
Filtered water	10.45 a.m.	72.5	23	2.3
Filtered water	11.15 a.m.	72.5		2.1
Filtered water	11.45 a.m.	61.5	26	2.6
Filtered water	12.15 p.m.	72.5		1.8
Filtered water	12.45 p.m.	61.5	28	2.3
Filtered water	1.15 p.m.	72.5		1.7
Filtered water	1.45 p.m.	72.5		1.7
Filtered water	2.15 p.m.	78.5		2.3
Filtered water	2.45 p.m.	84.5	28	2.7
Filtered water	3.15 p.m.	72.5	27	2.8
Filtered water	3.45 p.m.	72.5	26	2.3

* Analyses made at Mount Prospect Laboratory.

creased to 3.4 p.p.m. The rate was then lowered again, the use of soda ash still being discontinued, but the iron in the filtered water did not materially improve, ranging from 2 to 3 p.p.m.

Owing to the city's experience, however, the plant was continued in operation without the use of soda ash. Table 5 shows the results of analyses made upon samples taken every half hour during a run at a moderate rate of filtration. The iron in the filtered water ranged from 1 to 2.8 p.p.m.

The results for the first season could hardly be called satisfactory, and it was believed that several changes in the plant were necessary

for the second season's operation. A larger sedimentation tank was constructed 28 feet long, 21 feet wide and 12 feet deep. This tank was divided with baffles into seven compartments so that the water alternately moved rapidly downward and then slowly upward in order by changing rates of movement to obtain maximum sedimentation. However, it will be noted that comparatively little iron is removed by sedimentation, the process merely giving time for reaction and absorption of oxygen from the air.

The sand was also considered to be at fault and samples were obtained from firms in Massachusetts and New Jersey. The sand in the filter bed was replaced entirely with purchased sand, the bottom third receiving sand with an effective size of about 0.80 mm. and a uniformity coefficient of 1.65 and the upper two-thirds receiving sand with an effective size of 0.47 mm. and a uniformity coefficient of 1.40.

In order to have the plant ready for efficient service, experiments were started early and tests were made during an inspection trip on June 25, 1915, at the plant. The results of these tests are given in Table 6.

There were two periods of aeration and samples were taken before and after each and from each compartment of the sedimentation basin, also from the old sedimentation basin and aerator and from the filter bed with the filter running at about 50,000,000 gallons per acre per day. It will be noticed that about 4 p.p.m. of iron was removed by the aerators and about 4 p.p.m. by the sedimentation basin and about 7 p.p.m. by the filter beds. The filtered water still contained about 2 p.p.m.

The rate was then increased to about 125,000,000 gallons per acre per day. The aerators again removed about 4 p.p.m. of iron, the sedimentation basins, however, practically nothing, but the filters about 9 p.p.m., so that in the total effect the filters were nearly as effective at the high rate as at the low rate, but the water in neither case had opportunity to absorb sufficient oxygen to completely oxidize the iron, at least the oxidation was incomplete. It was advised that more aerators be installed so as to increase the number of splashes so arranged as to cause foaming of the water and trapping of air bubbles and giving the fullest opportunity for absorption of oxygen. The splashing is essential in order to get rid of the excess carbonic acid which is set free as fast as the iron oxidizes. The lack of oxidation was prettily demonstrated to the eye by the appearance of the

water in the large sedimentation basin when operating at the 125,000,000 gallons per acre per day rate. The reddish color of the water, due to hydrate of Fe_2O_3, present during the lower rate changed to a green color, due to hydrate of Fe_3O_4, even in the last compartment, indicating insufficient oxidation.

TABLE 6

Experimental tests during inspection made June 25, 1915, Rockaway Park

SAMPLE	CARBONIC ACID CO_2	IRON Fe
	p. p. m.	*p. p. m.*
Rate of filtration about 50,000,000 gallons per acre per day		
Raw water	40	17.0
After first aeration	36	18.4
After second aeration	36	16.0
Second compartment sedimentation basin	34	13.2
Third compartment sedimentation basin	36	13.0
Fourth compartment sedimentation basin	33	12.0
Fifth compartment sedimentation basin	39	12.0
Sixth compartment sedimentation basin	36	12.0
Seventh compartment sedimentation basin	36	11.0
Effluent, large sedimentation basin	38	11.0
Effluent, small sedimentation basin and aerator	30	9.0
Effluent filter beds	20	2.2
Rate of filtration about 125,000,000 gallons per acre per day		
Raw water	46	16.0
After first aeration	46	13.6
After second aeration	42	14.4
Second compartment sedimentation basin	38	12.0
Effluent, large sedimentation basin	36	12.4
Effluent, small sedimentation basin and aerator	36	12.4
Effluent filter beds	24	3.6
Standpipe	12	1.6
Mixed Rockaway Park supply	14	0.6

A series of cascades was arranged so that the water splashed and foamed nine times before entering the large sedimentation tank. This remedied the trouble completely as shown from the samples taken July 19, 1915, from the plant in regular operation, the filter effluent showing only 0.20 p.p.m. iron. These results are shown in Table 7.

TABLE 7

Tests of plant in regular operation with additional aerators, July 19, 1915
76,000,000 gallons per acre per day

	IRON	HARDNESS	Cl.	NITRATE
	p. p. m.	*p. p. m.*	*p. p. m.*	*p. p. m.*
Second compartment sedimentation tank	7.00			
Effluent, small sedimentation tank	8.80			
Filter effluent	0.20	29	44.8	0.00
Standpipe (outlet pipe)	0.30	26	44.0	0.05
Tap Fifth Avenue 4000 feet west of filter	0.40	20	44.0	0.10

An inspection trip was made August 17, 1915, and tests carried out, samples being taken from the raw water, from the water after aeration, from the water after sedimentation as it goes onto the filters and from the effluent of the filters. The plant was operated at two rates, 69,000,000 gallons per acre per day and 114,000,000 gallons per acre per day and the iron in the effluent from the filters at both rates was only 0.05 p.p.m. This result could not be improved upon. The results of these tests will be found in Table 8:

TABLE 8

Tests during inspection made August 17, 1915, Rockaway Park

	RATE OF FILTRATION			
	350 gallons per minute (69 m. g. a. d.)		650 gallons per minute (114 m. g. a. d.)	
	Free CO_2	Fe	Free CO_2	Fe
	p. p. m.	*p. p. m.*	*p. p. m.*	*p. p. m.*
Raw water	55	5.0	49	5.4
After nine aerators	41	5.0	40	5.4
After eleven aerators and sedimentation tanks (water to filter)	31	3.5	31	4.2
Effluent from filters	19	0.05	22	0.05

The removal of carbonic acid is also obvious in the above table, the more so when one considers that the oxidation of iron continually increases the free carbonic acid. This removal accompanies and materially hastens the absorption of oxygen by the iron.

Table 9 gives the complete chemical analysis of the water as it comes from the filter plant.

TABLE 9

Analysis of filtered water July 19, 1915, Queens County Water Company, Rockaway Park, L. I.

	p. p. m.
Turbidity	0
Color	2
Odor	0
Albuminoid ammonia	0.008
Free ammonia	0.060
Nitrite	0.001
Nitrate	0.00
Total solids	125
Chlorine	44.8
Hardness	29
Alkalinity	11
Iron	0.20

SUMMARY

Removal of iron by mechanical sand filters is very satisfactory, more than 20 p.p.m. being reduced to 0.10 p.p.m. or less, under proper operation. Rates of filtration are high, over 100,000,000 gallons per acre per day. Wash water is low and periods of run are long as compared with alum filtration.

The efficient removal of iron depends upon several factors:

Sufficient aeration, by suction of air, by splashing and foaming, by sedimentation tanks which give time for reaction, and by ripening of the sand by deposition of adhering iron oxide which probably acts catalytically as a carrier of oxygen.

Removal of carbonic acid, which is set free as the iron is oxidized. This is facilitated by splashing, and by contact with air during sedimentation and filtration.

Sand of the right effective size, about 0.50 to 0.60 mm. and as uniform as possible, preferably less than 1.8 uniformity coefficient.

The first stage of oxidation is to the hydrate or basic carbonate of Fe_3O_4 as shown by a green color. For complete removal of iron to the last traces this oxide must be fully oxidized to the hydrate of Fe_2O_3 as shown by a red color. The equation of complete oxidation by dissolved oxygen is as follows:

$$4\,FeCO_3.H_2CO_3 + O_2 + 4\,H_2O = 2\,Fe_2O_3 + 8\,H_2CO_3$$

whence it follows that 1.4 p.p.m. of dissolved oxygen will oxidize 10 p.p.m. of iron. There is usually sufficient oxygen in the water

to complete the oxidation of the iron. To cause the reaction to take place the chemical equilibrium must be disturbed, the carbonic acid being necessarily removed. This is really the most important part of the process. Splashing is the most effective and rapid method, exposure to air accomplishing it slowly. The correct size of sand fully ripened is also very important for the finishing process to complete the oxidation and adequately filter out the last traces of iron.

DISCUSSION

MR. R. E. MILLIGAN: The speaker understands that the experiments referred to were conducted by the city of New York at Rockaway Park, and that the general conclusion was that the iron removed by the filter was in a colloidal condition and that the iron deposited on the sand grains caused a further deposition when the applied iron came in contact with the iron already removed; also that it was shown that better results were achieved when no caustic soda or other alkali was used. Is this correct?

MR. FRANK E. HALE: Fully as good results were obtained by aeration alone as by the use of alkali. The precipitate caused by alkali tends to be colloidal and pass through the filters.

MR. R. E. MILLIGAN: How long has the plant been in operation?

MR. FRANK E. HALE: Two seasons, operating days only from June to August. The sand was changed at the beginning of the present season, because the sand used the first season was of improper quality.

MR. R. E. MILLIGAN: It would be interesting to know how long the bed was used before using alkali.

MR. FRANK E. HALE: No alkali was used this season, it was used only at the beginning of last season. The iron content was reduced from 17 or 18 to 2 p.p.m. last year, when using alkali, but was reduced to as low as 0.05 p.p.m. this season when no alkali was used.

MR. ROBERT SPURR WESTON: Will Mr. Hale please state whether he has ever found manganese or humic acid in any of the Long Island waters, which would interfere with the oxidation of the ground water containing iron?

MR. FRANK E. HALE: There is apparently no humic acid in any of the well waters. If there were there would be likely to be color and our well waters are colorless. Manganese is probably present in small amounts; we do not usually test for it. If present it should help the oxidation, as manganese in alkaline condition is a carrier of oxygen.

MR. ROBERT SPURR WESTON: The experience of Mr. Barbour at Lowell, Massachusetts, and Mr. Lounsbury at West Superior, Wisconsin, is of interest. There you cannot increase the oxygen above 50 per cent of saturation without affecting the deferrization process.

The question was asked to find out if any of the Long Island waters contain enough humic acid or manganese to interfere with the precipitation of the iron.

MR. FRANK E. HALE: This was an interesting study to the author, because at the two city plants there was no trouble in getting the iron out readily; while at Beasley's a certain amount of air leaks into the pump system, at Springfield this does not occur. There is no evidence of air leaking into it at all. The only chance for aeration is during sedimentation. When the Rockaway Park plant started it was, therefore, a surprise that we did not get good results at once. There were progressively put in larger sedimentation basins, then more aerators and then better sand, and the right effect was finally obtained. In the author's opinion the character of the sand affects the results seriously. Next season there will be a chance to leave the aerators going and cut out the sedimentation basin, and vice versa, in order to study the exact effect of each more closely with a ripened sand of proper character.

MR. ROBERT SPURR WESTON: Is there reason to suppose that the coagulation of the iron already oxidized is what happens rather than the oxidation? Does not the oxidation take place quite rapidly with the gathering of fine particles of hydrate into larger aggregations capable of being removed on the sand by a process which

takes time. For example, take two waters, both of which contain a large percentage of oxygen, showing a different time reaction; is not the coagulation involved in this case; and was not coagulation largely accelerated by the contact of accumulated hydrate with the finely divided hydrate in the plants mentioned in the paper?

MR. FRANK E. HALE: The iron hydrate, whether considered on top of the sand or about the sand grains is a factor in the oxidation, because there is not complete oxidation until the sand has ripened and remains coated; it cannot be washed off. There is no doubt that the precipitated iron oxide, accumulated as schmutzdecke, will give up a portion of its oxygen; this is certainly the case in corrosion of iron pipe. But there is a certain balance between the carbonic acid and the iron in the water which has to be disturbed. It would probably be called mass action. If there is an excess of carbonic acid before the water reaches the air the iron does not oxidize even though there is an excess of dissolved oxygen. The ripening of the sand is an important factor in getting complete iron removal.

A MEMBER: From the tables showing successful operation it would seem that most of the iron is removed on the filters and very little deposited in the settling basins. Will the author tell us how long that sand bed would last without replacement, and whether enough iron can be removed by agitation and wash to keep the replacement from taking place too often?

MR. FRANK E. HALE: No sand has been replaced in the four operations of the city plants.

The precipitated iron is readily removed by washing. The coating on the sand grains is a close adherent coating; it is not a thick coating, but a thin film.

A MEMBER: If the iron accumulates on top how can you get a catalytic action? This must take place in the sand bed itself, and that would necessitate some iron depositing on the grains where the action takes place. Does it not seem reasonable that if you get a precipitation due to the iron on the sand that you get iron deposited in the sand rather than on top of it?

MR. FRANK E. HALE: Experience does not show that it accumulates to a troublesome extent. Catalytic action refers to the giving up and taking up of oxygen by the iron repeatedly and may take place on top of the sand bed as well as in it.

MR. ROBERT E. MILLIGAN: In an experience of over twenty years, covering actual operation of iron removal plants, ranging from Massachusetts to Iowa, Illinois, Long Island, New Jersey and Maine, the necessity of the precipitation of iron with an alkali, preferably lime, has been conclusively shown. Even where this was done there was a creeping action throughout the sand bed which finally resulted in an increased amount of iron in the effluent; and in cases where no alkali was used the increase in the effluent was more quickly had. Upon examination of the filter beds at Freeport, Illinois, and at Quincy, Illinois, it was found that the iron had penetrated throughout the entire mass of the sand bed clear to the strainer system. At Quincy this was equally true of the lime used in conjunction with sulphate of iron to produce a coagulant. At Freeport lime only was used to remove iron in the ground wells forming the source of supply. In all iron removal plants this condition seems to pertain and it becomes necessary to remove the beds.

MR. FRANK E. HALE: How many years did it take?

MR. ROBERT E. MILLIGAN: In some cases two years, and in the case of Asbury Park, New Jersey, approximately ten years. In the latter case, however, double filtration is resorted to, using sand and animal charcoal, and the process is greatly assisted by the air lifts used to lift the water to the filters.

MR. FRANK E. HALE: The author's impression from his experience at Rockaway Beach was that the precipitated iron was so fine with the use of alkali that it penetrated the filter beds, but that it tended to a coarser, better precipitate with aeration alone. He had considerable difficulty in inducing Mr. Bettes to stop using soda. But the experience this year has shown that fully as good results are obtained without the use of coagulants.

MR. A. J. PROVOST, JR. (by letter): The paper presented by Mr. Hale brings out some of the most interesting of the problems related to deferrization of ground waters.

The two municipal plants referred to at Baisley's Pond and Springfield Pond of the Brooklyn water supply are good examples of the simplicity of iron removal from certain shallow subsurface waters, such as occur frequently on Long Island, New Jersey, etc. These installations also illustrate how an apparatus may clearly fail in the purpose for which it is designed, and still be of great service for some quite different purpose. Space may perhaps be permitted to briefly state the rather unique history of these two filter plants.

Prior to 1902 a portion of the Brooklyn supply was taken from surface waters stored in Baisley's Pond and Springfield Pond, both of which were subject to important pollutions which the city was unable to control.

A contract was entered into in 1901 for the installation of rapid sand filters from the contractors' designs for the purification of these supplies under guarantee as to sanitary efficiency. Tests conducted in 1901 and 1902 were unsatisfactory, and it was not until 1904 that the filters were accepted by the city, after material modifications had been made in the construction and operating features. In 1905 the Baisley's plant filtered on the average 4.25 m.g.d., at a cost of $6.53 per million gallons, and the Springfield plant filtered on the average 2 m.g.d. at a cost of $9.58 per million gallons. Both plants then gave a satisfactory degree of purification, although there were some operating difficulties.

By 1908 the average daily yield at Baisley's was only 2.8 m.g.d. at a cost of $12.98 per million gallons, and at Springfield only 0.9 m.g.d. at a cost of $13.24 per million gallons. The removal of bacteria in both plants during that year averaged about 98 per cent, and Coli were present in about 3.5 per cent of 10 cc. inoculations of the filtered water.

In 1909 the plants were reported in dangerous condition, due to lax supervision, and they were subsequently abandoned in favor of shallow wells which, it was expected, would collect the pond waters after sufficient natural filtration through the soil. These waters when so collected were found to contain prohibitive amounts of iron. The old filter plants were then changed somewhat and used for the removal of excess iron, with the very satisfactory results given in the author's paper.

The author has also given us an excellent example of one of the more difficult phases of deferrization. The various steps undertaken in working out and solving the Rockaway Park problem are interest-

ing and instructive. Here we have a water with no materially greater iron content, but with entirely different characteristics. Doubtless the carbonic acid content of this water is one of the important determining elements, although it is possible manganese is present and not determined and reported. The writer has had some recent experience with iron removal from water taken from wells about 550 feet deep at Jamaica, Long Island. The iron is present in amounts averaging about 2.5 parts per million, associated with manganese about two-third parts per million, and carbonic acid about 25 parts per million.

Although the water is raised from the well by air lift, and is in contact with air in the well for a period of about 2½ minutes before its discharge, and is further aerated by passing over a wier about 47 feet long, equivalent to about 10 gallons per minute per linear foot of wier as it enters the filters, it was impossible to remove a substantial proportion of the iron content by filtration, except by relatively slow rates after a considerable period of sedimentation, and it was impossible to reduce the iron and manganese to a satisfactory degree by means of rapid filtration except after neutralization of the carbonic acid by coagulation with lime for a substantial period. Analyses of the water, extending over an extended period, indicate a soft water with general absence of organic impurities and high in iron, manganese and CO_2. The normal iron fluctuates, but averages about 2.50 parts per million, as shown by twenty examinations during a period of four years, with a maximum of about 4 parts.

The apparatus used for iron removal with respect to which the following tests are reported, was designed by the writer, and consists of a filter 15 feet interior diameter, containing 28 inches Cape May sand, having an effective size of 0.43 mm., and a uniformity coefficient of 1.5.

The floor system is similar in principle to the ridge block strainer type, but is believed to embody some novel features. Wash water is used at moderate rates in combination with air. A balanced butterfly valve with float control regulates the rate of filtration. The sedimentation tank has a capacity of about 17,000 gallons, and is provided with baffles. Water from the well is discharged into the sedimentation tank head box where it is dosed with the coagulant solutions.

The following table gives the essential data relating to the conditions of the tests and the results secured:

	RATE OF FILTRATION—MILLION GALLONS PER ACRE PER DAY	COAGULATION PERIOD	COAGULANTS—GRAINS PER GALLON			RAW WATER—PARTS PER MILLION				FILTERED WATER—PARTS PER MILLION				IRON REDUCED
			Alum	Soda Ash	Lime	Alkalinity	Hardness		Iron	Alkalinity	Hardness		Iron	
							Temp.	Perm.			Temp.	Perm.		
		minutes												*per cent*
July 16–29, 1915	169	30	0.5	0.5					1.8				0.9	50
August 5, 1915	125	45	0.5	0.5					0.7				0.5	30
	50	120	0.5	0.5									0.2	70
August 11, 1915	169	30			1	30.2	22.5	15.0	3.0	37.5	23.8	17.3	0.4	86
	169	30			2					45.9	67.4	21.2	0.25	92
	125	45			1						35.1	19.9	0.3	90
	125	45			2						28.7	23.8	0.05	98
September 20, 1915	169	30			1.5				2.20				0.2	91

The conclusions drawn from these tests were:

That it is not feasible to remove a sufficient amount of the iron, manganese and CO_2 content by filtration at high rates after coagulation with alum and soda ash in reasonable quantities without a prohibitive period for coagulation and oxidation.

That it is feasible to absorb the CO_2 and to remove substantially all the iron and manganese by filtration at high rates (125 to 169 million gallons per acre day) if preceded by coagulation with lime at the rate of 1 to 1.5 grains per gallon, and a period of coagulation and oxidation of from one-half to three-quarters of an hour without increasing the hardness of the water beyond that of other important local supplies which are considered soft.

The author is to be complimented for having made available the results of the experiments at Rockaway Park in the clear manner in which they are presented. It is quite evident that with brief sedimentation rapid filtration was unsatisfactory, even when large amounts of soda ash were used to neutralize the CO_2, and that with greatly increased sedimentation and elaborate means for aeration, satisfactory results were accomplished without the use of coagulant. It would have been of added interest if, after the installation of the large sedimentation tank, relatively small amounts of lime had been tried in order to determine whether the expense of aeration rendered it an economical substitute.

The author is quite correct in characterizing the use of native sand as an unwise procedure. The writer has examined the characteristics of a large number of sands from more than twenty different localities on Long Island, and has found none which could be successfully used for rapid filters except after a prohibitive amount of washing and screening. It is better to pay a higher price and secure an article that will give satisfactory service.

The author's paper emphasizes the importance of careful scientific investigation preliminary to the design and construction of all permanent iron removal plants.

Not all of these problems are alike or even similar, and it is quite probable that insufficient attention has been given in many instances to the important effect which associated minerals, such as lime, manganese and CO_2 have in the interference with successful iron removal.

MR. FRANK E. HALE: In the plant at Jamaica, Long Island, Mr. Provost does not appear to have tried splashing-aeration in

place of the use of chemicals. As stated in the paper, the chief difficulty is to get rid of carbonic acid. The extra head pumped for aeration at Rockaway Park is less than 10 feet. With an economical pumping plant this extra head would not cost more than 55 cents per million gallons, which would mean at Rockaway Park about 33 cents a day. If lime were used, probably about 3 grains per gallon would be needed, which, alone, would cost $1 a day. Consequently, it is cheaper to pump the extra head than to purchase lime, to say nothing of the trouble and labor in apply ing the lime.

The presence of manganese would not have any bearing upon any questions of difficulty in removing iron, since in alkaline solution manganese readily absorbs oxygen and passes to hydrated dioxide. In fact this reaction is the basis of the Winkler method for determining dissolved oxygen in water. Furthermore, manganese is removed from water supplies in Europe by similar oxidation on beds of manganese permutite.

WATER SOFTENING PRACTICE[1]

SAMUEL A. GREELEY

During the last year, the writer has had occasion to investigate water softening practice in connection with the development of two water supplies. A considerable amount of data was collected and tabulated, particularly as regards municipal water softening plants. Since these data may be of interest and some service to water works men, they are presented herewith. It is largely a review of present day practice in water softening as applied to municipal supplies and includes a few memoranda on the characteristics of hard waters. Certain special points are emphasized in the light of experience after a number of years of operation of municipal water softening plants.

Water softening should be a subject of special interest to water works men in Illinois and throughout the middle west, where hard well water supplies are so frequently used. Some statistics of Illinois water supplies showing the number of supplies from different sources are therefore of interest. From the McGraw-Hill Water Works Directory, 1915, it appears that in Illinois there are 214 well water supplies of which 72 are from wells less than 100 feet deep, the balance ranging in depth up to more than 2000 feet. Seventy-two supplies are from surface waters, of which twenty are taken from Lake Michigan. Of these supplies, twenty-one surface waters are filtered and two only are softened, those at Freeport and Hinsdale. The plant at Hinsdale is the most recent, having gone into operation in the summer of 1915. The plant at Freeport is more of an iron removal plant than a softening plant.

The desirability of water softening does not depend on sanitary grounds so much as on economic grounds. Within ordinary limits, the hardness of water has little effect upon the public health. However, for both industrial and household uses, hard water is costly. In particular the quality of a municipal water supply for industrial purposes assumes importance where towns are competing for the

[1] Read before the Illinois Section of the American Water Works Association, October 19, 1915.

location of industrial plants. Some towns now depend upon railroad shops and roundhouses or large manufacturing plants for considerable portions of their population. The progressive city with an ample soft water supply will grow while others will stand still.

There is, however, a more direct economic aspect. For certain conditions, depending upon the hardness of the water, the size of the supply and other local items, a town will save money by softening its water. The relation between the cost of softening water and the financial saving which results is very direct, depending upon the character of the water, the size of the plant and the general efficiency of operation. At St. Louis it is estimated that the saving from soap alone amounts to $496 against a total cost of purification amounting to $424 per day.

Hard waters are objectionable in many ways. For domestic use they require larger quantities of soap, they are unsatisfactory for washing, have an annoying effect on the skin and increase the plumbing bill. For boiler use, they cause trouble by forming scale in the boilers, cause interruption in service, shorten the life of boilers and fire boxes, and increase the fuel bill. In certain special industrial processes, hard waters are considerably less satisfactory than soft waters. It is likely, therefore, that increasing competition for industrial growth and rising standards for domestic water supplies will lead to a substantial growth of water softening.

HARD WATER

Rain water, which is initially pure and soft, acquires mineral constituents as it percolates through the soil. Some of the minerals are dissolved by the water and others are held in solution by free and half bound carbonic acid (CO_2) in the water. Carbonic acid, or carbon dioxide, is taken up by the water as it falls through the air and from decaying vegetable matter in the soil. It occurs in water in the free state or in the bicarbonate or carbonate form. All of these forms include substances soluble in water. The bicarbonate form refers to the carbonates held in solution by an equivalent quantity of the carbonic acid, such for instance as calcium bicarbonate ($CaCO_3H_2CO_3$). The carbonates of calcium and magnesia are thus held in solution by conversion into the bicarbonate form. The carbonate form is represented by sodium and potassium carbonates which are directly soluble in water.

The mineral content of waters, therefore, depends upon the character of the soils and rocks through which the water has percolated before it is tapped as a source of supply. Igneous rock formations contain a comparatively large proportion of the metals of the alkalies such as sodium and potassium. Secondary rocks formed by sedimentation, on the other hand, contain a larger proportion of the alkaline earths, such as calcium and magnesium. Among these secondary formations are the limestones, dolomites, sandstones, shale, gypsum, glacial deposits, etc.

Iron occurs quite generally in both primary and secondary formations and frequently in gravels and sands. Its most common form is hematite (Fe_2O_3). Water, which has given up its oxygen content to decaying organic matter in the soil, will reduce the iron from the ferric to the ferrous oxide (FeO). Carbonic acid in the water combines with the ferrous oxide to form ferrous bicarbonate ($Fe(HCO_3)_2$) which is soluble in water. Iron in water causes discoloration, and in large quantities is objectionable.

Salt and gypsum occur in large deposits not quite so universally distributed as iron. Water passing through or over these deposits takes up the chlorides and sulphates of sodium, calcium and magnesium, all of which are soluble in water.

From these and similar sources, soft rain water is converted into more or less hard water. Obviously hard waters are chiefly derived from deep and shallow wells, although waters from lakes and rivers often contain a considerable hardness.

MINERAL CONSTITUENTS

There are thus a large number of mineral constituents of water. The principal ones which are dissolved by the water itself are the following:

1. Calcium sulphate, sometimes called gypsum, or plaster of paris ($CaSO_4$).
2. Calcium chloride ($CaCl_2$).
3. Magnesium sulphate, sometimes called Epsom salts ($MgSO_4$).
4. Magnesium chloride ($MgCl_2$).
5. Sodium sulphate, sometimes called glauber salts (Na_2SO_4).
6. Sodium chloride, or common salt (NaCl).
7. Sodium carbonate or washing soda (Na_2O_3).
8. Small quantities of the nitrates of sodium, magnesium and calcium.

In addition, water will dissolve some organic matter and other impurities.

Among the constituents which are held in solution by water containing carbonic acid are the following:

1. Calcium carbonate, sometimes called chalk or marble ($CaCO_3$).
2. Magnesium carbonate ($MgCO_3$).
3. Ferrous iron oxide (FeO).
4. Aluminum, which is generally dissolved in very small amounts.

In solution these constituents occur in the bicarbonate form, as already noted. The iron is dissolved by a reduction process in water which is deficient in oxygen.

In addition to these principal mineral constituents, waters may contain sulphuric acid, tannic and acetic acids, hydrogen sulphide gas, suspended matter, oil and other impurities.

TERMINOLOGY

For convenience in studying chemical analyses and reactions, and in the use of literature on water softening, some of the more frequently used terms are described.

1. Total hardness. This term is used to indicate the quantity of certain soluble mineral constituents consisting chiefly of the salts of calcium and magnesium. It is generally measured by the soap consuming power of the water. When sodium or potassium soaps are added to hard water, the soap is decomposed and insoluble soaps of lime and magnesium are formed. These form the unsightly scum on the sides of containing vessels. Until the insoluble soaps are precipitated, no lather will form. Thus, hard waters require the use of more soap for successful washing. In precise terms, total hardness, as generally determined, means the soap consuming properties of the water. Both carbonates and sulphates are included in this term.

2. Temporary hardness. As already noted, the solubility of calcium and magnesium carbonates depends upon the presence of carbonic acid. If the carbonic acid is driven off by boiling the water, the bicarbonates revert to the carbonate form and are precipitated. It should be noted that the precipitation will not be complete and portions of the carbonates of calcium and magnesium will remain dissolved even after prolonged boiling. By boiling, therefore, the hardness of the water is reduced. The hardness thus removed is spoken of as the temporary hardness.

3. Permanent hardness. The mineral constituents which remain in the water after prolonged boiling, form the permanent hardness. This hardness is due largely to the chlorides and sulphates of lime and magnesium and to the carbonates of these bases remaining in solution.

4. Alkalinity. Alkalinity in water is caused by the presence of certain salts of the alkalies and alkaline earths. It is measured principally by the carbonates of sodium and potassium and the carbonates and bicarbonates of calcium and magnesium. The hydrates of these salts also add to the alkalinity, producing what is termed caustic alkalinity. The alkalinity differs from the temporary hardness, by measuring the amount of hydroxyl ions present while the hardness is limited to the salts having a soap consuming power. It will ordinarily run higher than the temporary or "carbonate" hardness because the hydrates are included, although the difference is not generally great.

5. Carbonic acid (CO_2). That portion of the carbon dioxide which is in chemical combination with the carbonates of calcium, magnesium, iron and alumina to form bicarbonates is called half-bound. Any excess in the water over this amount, and over that present strictly as carbonate, is called free carbonic acid. Of the carbonic acid in the bicarbonates, one-half is half-bound, the other half being true carbonates.

Free carbonic acid has a corrosive action on service pipes, particularly lead and galvanized iron. The corrosive action is stronger in soft water than in hard because calcium carbonate forms a protective coating on the inside surface of the pipe.

6. Incrustants. This term is synonymous with permanent hardness. It includes the sulphates, chlorides and nitrates of lime and magnesium. The solubility of these salts is not affected by boiling the water. But when a water is evaporated, as in steam boilers, the concentration increases until the water can no longer hold the salts in solution and a hard incrustation or scale is formed. At a temperature of 70° F. one part of calcium sulphate is soluble in 390 parts of water. Some authorities state that the solubility of calcium sulphate becomes less as the temperature increases, but it is generally agreed that concentration is required for its precipitation.

7. Acidity. Some waters contain free acids, which give the water an acid reaction. These acids include free sulphuric acid from industrial pollution and from the sulphates of iron and alumi-

num. The acidity can be determined by titration against a standard sodium carbonate solution, the acidity being expressed in terms of equivalent sodium carbonate required to neutralize the acidity.

ACTION OF HARD WATERS

The action or effect of hard waters depends upon the service and also upon the character of the water. The more important actions of hard waters are described below.

Boiler Shale

When the mineral constituents of water are precipitated from solution within a boiler, a scale is formed which will be hard or soft, depending upon the composition of the water.

Calcium carbonate, when present alone, is generally deposited as a soft scale. Its precipitation begins at a temperature of about 130° F., so that it will be deposited in feed water heaters, condensers and feed water lines as well as in the boiler. With other constituents, it often combines to form a hard scale.

Magnesium carbonate though more soluble than calcium carbonate, is not entirely precipitated except by the concentration of the water. It is, therefore, deposited chiefly in the boiler as a soft mud or scale. Parts of it which are deposited on the hot surfaces of a boiler are changed by the heat into magnesium hydrate or oxide, both of which form hard scales.

Calcium sulphate forms a very hard scale which results from the combined effect of heat and concentration, and is found only in boilers. Magnesium sulphate is not a scale forming constituent because it is very soluble in hot water. But when calcium carbonate is also present in the water, a reaction takes place which results in the formation of magnesium hydrate and calcium sulphate, both forming exceptionally hard scales.

Iron and aluminum oxides form scale by precipitation from the soluble bicarbonate form, just as calcium carbonate is precipitated from the bicarbonate. However, on heating they are changed to the oxide form.

Silica, suspended matter and organic matter add to the thickness of scales by becoming cemented with other scale forming constituents.

Foaming

Foaming of water in steam boilers is chiefly a mechanical action produced by interference with the bursting of the steam bubbles so that small drops of water are carried off with the steam. The principal cause is the presence of suspended matter in the water which produces the interference by forming a surface scum on the water. The same action results when calcium and magnesium carbonate are precipitated in a light flaky condition. The foaming is more active if the water contains comparatively large amounts of soluble salts or organic matter. The amount of foaming also depends upon the type of boiler and the methods of operation. Foaming will increase as the concentration of the water increases in the boiler.

Corrosion

There are two forms of corrosion. One occurs in the cold in pipes. It is produced by the presence of hydrogen ions and dissolved oxygen in the water. All acids have a tendency to form hydrogen ions by dissociation. They attack metallic iron and dissolve it in the ferrous form (FeO). This is then oxidized by the oxygen to the ferric form (Fe_2O_3) and appears as iron rust. This action takes place to some extent with pure water and is not strictly associated with water softening problems.

The second form of corrosion takes place in boilers. The most active element in this form of corrosion is sulphuric acid. This attacks the boiler iron, forming soluble iron sulphate. The heat in the boiler splits this up into iron hydrate and free sulphuric acid, so that the process continues indefinitely. Other free acids as well as the sulphates of iron and aluminum are corrosive in this same way.

Carbonic acid also has a corrosive action which generally takes the form of pitting. This gas is set free from the bicarbonates by boiling and under a combined action with the heat, moisture and oxygen present in a boiler pits the metal wherever it has attached itself to the inner surfaces of the boiler.

The chloride constituents also are corrosive. Magnesium chloride, for instance, under boiler pressure, is decomposed into magnesium hydrate and hydrochloric acid which attacks the boiler metal to form soluble chloride of iron. It will eat out the metal of stove tanks.

Fatty acids in a boiler, due to the saponification of animal or vegetable oils, used for lubricating for instance, are other causes for active corrosion.

Deposits

Hard waters will form deposits or incrustations in mains, service pipe, valves, meters, etc., causing considerable trouble and work for plumbers. In the softening process, deposits sometimes occur due to incomplete reactions at the softening plant. These deposits are largely lime. In a similar way, sand grains in filters become incrusted and deposits may also occur in the filter sand and underdrains. The size of sand grains is thus enlarged and the depth of the filter increased. The action is sometimes prevented by adding carbon dioxide to the softened water.

Soap consumption

The harder the water, the more soap will be required for satisfactory washing. The action of the soap in hard water is really a softening reaction. Experiments by Whipple indicate that with a water containing 200 parts per million of hardness, the average soap will soften about 24 gallons. In other words, this proportion of soap must be added to the water before a lather is formed. This is equivalent to about 20 tons of soap per million gallons of water used. If soap is worth 5 cents per pound, this is equivalent to $2000 per million gallons. If we assume that only a hundredth part of the water supply is used with soap, the actual saving will be $20 per million gallons. If the water is harder, the saving will be greater; and if the softening is not complete, the saving will be less. This saving can be balanced against the cost of softening the water. In table 4 it appears that the cost of softening water varies from $10 per million gallons up to $30, exclusive of fixed charges, which would add from $4 to $5 per million gallons. On soap saving alone, therefore, the cost of softening water is often justified. In addition, other less tangible savings should be included. In communities which use more soap, the saving will be increased.

THE SOFTENING PROCESS

General

A hard water may be softened by precipitating out the hardening mineral constituents, or by changing them into substances which do not harden the water. The former process is accomplished by the addition of lime (CaO_2H_2) or soda ash (Na_2CO_3) or both. The second process is accomplished by passing water at a proper rate through crystals of an artificial or natural zeolite such as "Permutit."

Reactions

Temporary or carbonate hardness is removed by adding to the water a suitable quantity of lime water. This process was discovered by Clarke in 1841. The lime combines with the free and halfbound carbonic acid and forms a precipitate of calcium carbonate in the form of a fine granular solid. Not only the lime originally present in the water as bicarbonate is thus precipitated, but also the lime which has been added to the water. The reactions are indicated by the following expressions:

$$CO_2+CaO_2H_2 = CaCO_3+H_2O$$
$$CaCO_3H_2CO_3+CaO_2H_2 = 2CaCO_3+2H_2O$$
$$2NaHCO_3+CaO_2H_2 = CaCO_3+Na_2CO_3+2H_2O$$
$$MgCO_3H_2CO_3+2CaO_2H_2 = 2CaCO_3+MgO_2H_2+2H_2O$$

Permanent hardness requires the addition of soda or both soda and lime water for its removal. If the permanent hardness is due to calcium salts, sodium carbonate is sufficient. But if the hardness is due to the presence of magnesium salts, both chemicals must be added. The reactions are indicated by the following expressions:

$$CaSO_4+Na_2CO_3=Na_2SO_4+CaCO_3$$
$$MgSO_4+Na_2CO_3+CaO_2H_2=Na_2SO_4+CaCO_3+MgO_2H_2$$

Of the products of these reactions, calcium carbonate and magnesium hydrate, which appear as precipitates, are removed by sedimentation and filtration. The sodium sulphates and carbonates remain in solution and are harmless in the amounts ordinarily present.

Nature of reactions

The chief product of these reactions is calcium carbonate. This is soluble in water to the extent of about 30 parts per million, so that it is impossible to remove the hardness completely.

The reaction of the lime salts takes place directly. When magnesium carbonate is present, however, the first product is a mixture of carbonates and hydrates of magnesium which are more or less soluble. Sufficient additional lime must be added to form magnesium hydrate as an insoluble gelatinous precipitate.

Time of reactions

The time required for the completion of these reactions is of considerable importance. If the reactions are not completed after-precipitations will occur, causing deposits in filter underdrains, distributing mains and valves, and in service pipes and meters. These deposits often cause considerable inconvenience.

This feature is probably more important in municipal service than in industrial service. In railroad supplies, for instance, the softened water is often stored in tanks before use and its use is largely restricted to engine boilers. Opportunities for troublesome deposits are not so numerous as in municipal water systems. Improvements over the hard raw water often induce superintendents to overlook troubles from after-deposits.

Estimates of the necessary time to allow for the reactions vary from three hours to six days. Most of the stock water softeners, such as are built for industrial and railroad service, provide from three to six hours coagulation and sedimentation based on the rated capacity. Experience at the Oberlin, Ohio, plant indicates that with four days in the settling basins, after-precipitation occurs to a moderate extent. Tests made with a six day period showed practically no after-reactions. This experience and others are given more at length under the caption "Results in Practice."

The time for the reactions depends on the character of the water, the intimacy of the mixture of the chemicals and the water, on the temperature and on other local factors. It is also probable that the reaction is promoted by mechanical agitation. This not only hastens the reaction, but also increases the degree of completeness. This result may be accomplished in closely baffled

mixing basins and in other ways. It appears, also, that the addition of a small amount of a coagulant such as aluminum sulphate causes a greater reduction in the alkalinity of lime treated water than the theoretical reaction would indicate.

Whipple states that the magnesium reaction takes place more rapidly than the calcium reaction. He finds that after-deposits are composed chiefly of calcium carbonate and contain very little magnesium.

All these features are necessary considerations in the design of a water softening plant.

Zeolites

Zeolites are minerals consisting of hydrated silicates of aluminum with alkalies and alkaline earth. A zeolite has the power of exchanging its base for that of another salt.

Permutit, which is manufactured for water softening purposes, is an artificial zeolite. Sodium permutit is a hydrated sodium silicate, the composition of which can be expressed as follows:

$$2SiO_2Al_2O_3Na_2O6H_2O$$

It is manufactured by fusing a mixture of feldspar ($KAlSi_3O_8$) kaolin ($H_4Al_2Si_2O_9$), pearlash (K_2CO_3) and soda, mixed in definite proportions. The product is porous and granular. A manganese permutit can also be prepared for use in removing iron.

Water softening by permutit or other zeolite is very different from the lime and soda process. The apparatus used is similar to a sand filter of the pressure type and can be "cut in" on a main supply line. The zeolite, however, takes the place of the sand in the filter. A typical cross section is shown in figure 1. At the top is a perforated tray holding a layer of gravel or marble chips. Below this is an open space and then the permutit resting on gravel and another perforated platform. The layers of gravel do not act as filters to remove turbidity. Experience with Lake Michigan water at the Union Stock Yards, Chicago, demonstrates the necessity of removing the turbidity from the raw water before softening it.

The calcium and magnesium salts forming the hardness of the water are not precipitated as in the lime-soda treatment, but are converted into sodium salts which are soluble and nonscale forming. After a time the permutit will have exchanged its sodium to an

economic limit, and "regeneration" will be necessary. This is done by passing a solution of common salt (NaCl) through the permutit and reconverting the calcium and magnesium permutit back to sodium permutit. The regeneration process takes about ten hours, so that the net softening period for one apparatus is 12 to 14 hours per day.

The rate of softening depends, of course, upon the character of the raw water. Hoover and Scott at Columbus report that, with raw water having a total hardness up to 392 parts per million, the

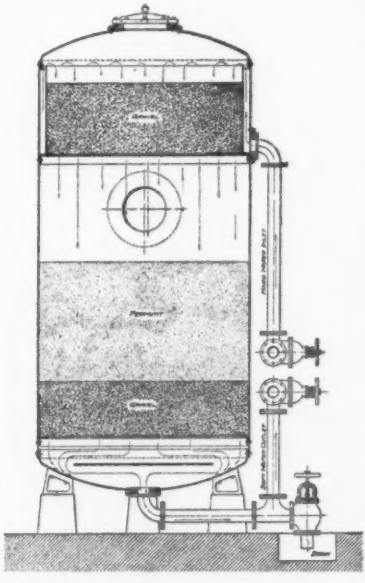


FIG. 1

highest efficient gross rate of filtration was 55,000,000 gallons per acre per day, giving a net rate of about 25,000,000 gallons per acre per day.

By this process a water can be completely softened. Calcium and magnesium can also be nearly completely removed by treatment with lime and soda, if they are added in large excess. But this is impracticable, because the excess of these chemicals in the softened water would generally be objectionable. With permutit, however, the softening reagent is insoluble and a large excess can be used. Hoover and Scott, in their experiments with permutit,

found it advisable to use about 16 times as much permutit as the theoretical quantity.

The experiments made at Columbus tested the applicability of the zeolite process for softening Scioto River water, which has a hardness of about 350 to 400 parts per million. The results are summed by Hoover and Scott as follows:

Advantages

1. It is the only practical process, known to the writers, by which water of zero hardness can be produced on a large scale.
2. Only one chemical is needed (common salt).
3. Variations in the hardness of the raw water are automatically taken care of.

There is no sludge to be removed.

Disadvantages

1. Cost of operation is higher than with lime and soda ash. For waters requiring a large amount of soda ash for softening, the cost of zeolite will compare more favorably.
2. Water to be softened must be perfectly clear, for if it contains any turbidity, the pores of the permutit become clogged.
3. The permutit softened water contains residual sodium bicarbonate, and if used for boiler feed purposes, may cause trouble by foaming.

ILLINOIS WATERS

As already pointed out, a variety of waters are used for public water supplies in Illinois. Analyses of waters typical of several different sources are given in table 1. These analyses, of course, are not applicable to any particular water and do not show variations in the character of the water. The Pottsdam waters seem to have less sulphate and more carbonate hardness than the St. Peters waters, although exceptions have been recorded.

The actual construction of water softening plants has developed not only in industrial service but also to a considerable extent in municipal service. At the present time there are upwards of ten municipal water softening plants in operation in this country. These two kinds of service are often quite different and these differences are interesting.

TABLE 1

Mineral analyses of typical Illinois water supplies—parts per million*

CONSTITUENTS†	LAKE MICHIGAN	SHALLOW WELL 100 FEET DEEP	WELL FROM THE ST. PETERS STRATA	WELL FROM THE POTTSDAM STRATA
Sodium nitrate	2.3			
Sodium chloride	5.9		24.1	8.9
Sodium sulphate	4.9	94.8	40.5	13.9
Magnesium sulphate	6.8	141.4	75.0	1.5
Magnesium carbonate	32.6	31.5		116.5
Calcium carbonate	82.1	395.3	70.2	193.4
Calcium sulphate			187.0	
Oxide of iron and aluminum	3.6		3.8	0.3
Silica	4.6	4.2	0.4	10.3
Total solids	143.0	700.3	481.3	352.4

* Data from Illinois Geological Survey and Water Survey Reports.
† List of constituents contains only principal salts.

Industrial service

A very large number of softeners have been installed for railroads, laundries and industrial establishments. Many of these have been built by concerns which make a specialty of building and installing water softeners and there are a number of excellent "makes" on the market. Others are installed by the railroads themselves.

The service is generally more direct than municipal service. In railroad service the softened water is stored in a tank and delivered directly to the locomotive boiler. With manufacturing plants, the distribution is somewhat more extended but not so much so as in municipal supplies. In locomotive boilers, the tendency to foam is greater than in stationary boilers. Soap is not used so much in the industries, except laundries. For each of these services, therefore, the treatment should be properly adjusted. A municipal supply which embraces many users, should be carried out with great care.

Municipal service

The design of a water softening plant for this service includes the following principal features:

1. Handling of chemicals.

2. Chemical feed apparatus.
3. Mixing chemicals with raw water.
4. Provision for the chemical reaction (coagulation) and sedimentation.
5. Filtration.
6. Sludge handling.
7. Disposal of waste water.

It is not within the scope of this paper to discuss the design of these features in detail. However, a few interesting notes are given which have developed from the information received.

TABLE 2

Operating data, municipal water softening plants, October, 1915

PLANT	AVERAGE HARDNESS OF RAW WATER	POPULATION 1910	QUANTITIES		PERIOD FOR REACTION AND SETTLING, BASED ON ACTUAL QUANTITIES	REMARKS ON AFTER PRECIPITATION
			Rated	Actual		
	p. p. m.		*m. g. d.*	*m. g. d.*	*hours*	
St. Louis, Mo.	170	687,029	160	100	40–60*	No trouble since filters have been in operation.
Columbus, O.	300	181,511	30	18.4	20.6	
Grand Rapids, Mich.	235	112,171	20	14.	3½ to 3	Requires careful operation and mixing. Alum used.
McKeesport, Pa.	100–600	42,694	10	3.6	7½ to 20	Incrustation of filter sand. No deposits in mains.
Owensboro, Ky.	300	16,011	3	1.5	48	Some precipitate. Not enough to cause trouble.
Oberlin, O.	300	4,365	0.75	0.28	48	Incrustation of filter sand.
Daytona, Fla.	360	3,082	0.30	0.17	4 to 18	A little trouble reported, especially when settling period is short.
Hinsdale, Ill.	360	2,451	1.00	0.30	20 to 40	
Port Tampa, Fla.	640	1,343	0.24		12†	

* Depends on basins in service.
† Based on rated capacity.

General statistics of municipal plants now in operation are shown in tables 2 to 4.

1. Chemical handling. In a number of small plants it has been found that hydrated lime in bags is more convenient to handle and store than lump lime in barrels or in bulk. At Columbus it was found that lime stored in bags for a long time became air slaked and lost strength.

Most of the chemical tanks are fitted with mechanical agitators. At Hinsdale, where slaked lime is used, one tank serves for both lime and soda solutions. There is a motor driven agitator in the tank. This is a quite general practice.

2. Chemical feed. A number of devices for controlling the chemical feed are available. At Hinsdale the raw water is pumped at a constant rate and the control consists in the discharge of a definite amount of the chemicals while the pumps are running. Variations in the flow are taken up in the water storage tanks. The control

TABLE 3

First cost of municipal plants in America, October, 1915

PLANT	DATE OF ERECTION	POPULATION 1910	QUANTITIES		COST OF CONSTRUCTION		REMARKS
			Rated	Actual	Total	Per million gallons rated capacity	
			m. g. d.	*m. g. d.*			
St. Louis, Mo.....	1915	687,029	160	100	$1,495,000	$9,344	Cost approximate*
Columbus, O.....	1906	181,511	30	18.4	590,780	19,693	First-class construction
Grand Rapids, Mich...	1910	112,171	20	14.0	449,569	22,478	First-class construction
McKeesport, Pa.....	1908	42,694	10	3.6	250,000	25,000	First-class construction
Owensboro, Ky.....	1906	16,011	3	1.5	30,000	10,000	Excelsior filter
Oberlin, O.....	1903	4,365	0.75	0.28	12,000	13,300	Pressure filter
Daytona, Fla.....		3,082	0.30	0.17	4,304	14,347	No filters
Hinsdale, Ill.....	1915	2,451	1.0	0.30	18,000	18,000	Filters 18 inches deep
Port Tampa, Fla.....	1914	1,343	0.24		7,000	29,100	No filters

* Existing work also used, but not included in figures.

apparatus consists of a floating orifice submerged below the surface of the chemical solution at the proper depth to take off the chemicals at the desired rate. A control tank stands near the chemical solution tank. This tank is filled by raw water which flows into it while the main pumps are running. The rate of filling this tank is controlled by a divided weir. There is a float in the tank which is connected with the floating arm in the chemical solution tank by a wire and pulleys. As the control tank fills the floating orifice is lowered, so that the rate of applying the chemical is proportioned at will by regulating the rate of filling of the control tank. When

the control tank is full, the contained water is wasted to a sewer. The effluent from the chemical solution tank is pumped to the raw water at the top of the settling tank.

In another apparatus, the chemical solutions are pumped from the tanks to a chemical regulator above. The regulator contains a cutoff weir which divides the flow of chemical, one part flowing to the raw water and the other returning to the chemical solution tanks. The position of this weir is determined by a float in a control basin located below the regulator box. The raw water passes

TABLE 4

Annual cost of operation and chemicals used, municipal water softening plants, October, 1915

PLANT	POPULATION 1910	ACTUAL QUANTITY, MILLIONS OF GALLONS PER YEAR	AVERAGE HARDNESS OF RAW WATER	CHEMICALS USED—POUNDS PER MILLION GALLONS					OPERATORS REQUIRED, TOTAL	COST OF OPERATION PER MILLION GALLONS
				Lime	Soda ash	Iron	Alum	Hypo		
			p. p. m.							
St. Louis, Mo.....	687,029	34,656	170	800		415		1.6	35	$4.56†
Columbus, O.....	181,511	6,716	300	1384	1054		260	4		17.46
Grand Rapids, Mich.....	112,171	4,506	235	1250			120		16	11.34
McKeesport, Pa.....	42,694	1,314	100–600	100 to 3500	100 to 6000	50 to 200	75 to 400			27.57
Owensboro, Ky.....	16,011	547	300	2000	75			1	2	10.05
Oberlin, O.....	4,365	102	300	2045	735				1*	13.49
Daytona, Fla.....	3,082	62	360	2910	250				1*	23.80
Hinsdale, Ill.....	2,451	100	360	4091	1368		small amount		1*	30.00

* Part time of one man.
† Does not include pumping.

through the control basin and into the mixing basins over "Sutro" weirs. These weirs are so constructed that the quantity of water flowing over them is directly proportional to the head. This apparatus, therefore, takes care of a variable flow of raw water. At the Owensboro, Kentucky, plant where this control apparatus is used, the lime and soda solutions are made up in one tank.

In another device, a constant head of chemical solution is maintained in a control box by pumping an excess of solution and providing the box with an overflow. The outlet is through an orifice at the bottom in which a tapered plug moves. Thus the quantity of

solution depends upon the position of the plug and this is determined by the quantity of water flowing through a Venturi meter.

At other plants small orifice feed boxes fitted with ball-cocks are used. The type for each condition depends upon the size of the plant, the cost and other local factors.

3. Mixing basins. Mixing basins, sometimes spoken of as softening tanks, are practically always provided. Two types are generally used. One promotes the mixture of the chemical solutions and raw water by mechanical agitation and the other by baffling.

At the Owensboro, Kentucky, plant there are four mixing basins, each containing four sets of agitators. The period in these four basins is one hour. At Daytona, Florida, the mixing is promoted by compressed air which is allowed to bubble through the mixture of chemicals and raw water.

At St. Louis, Columbus, Grand Rapids and McKeesport baffled mixing basins are used, providing mixing periods of about one hour on the rated capacity.

Some of the manufactured softeners provide mechanical agitation for a few minutes near the top of the inlet to the softening tank.

4. Provision for reaction and settling. As already indicated, municipal water softening plants have been designed along somewhat more liberal lines than manufactured softeners, especially as regards the time allowance for the reactions of the chemicals and for settling. The period provided in a number of operating plants is shown in table 2. The general experience indicates that troubles with after deposits grow less as the time allowance increases.

Ample provision for settling is undoubtedly costly and for this reason the design of the coagulating and settling basins should be made with great care. It frequently happens that the actual period or flowing through time is considerably less than the displacement period. This difference should be reduced as far as possible by proper design and operation. In cold weather, this feature assumes greater importance.

The point is illustrated by results of analyses made at the Oberlin, Ohio, plant by the state board of health (table 5).

5. Filtration. Filters are generally built with water softening plants to remove the precipitated salts and also the turbidity. Frequently they would be required for clarification and bacterial removal even if there were no softening. At Daytona, Florida, however, no filters are used. At Owensboro, Kentucky, the filters

are made of excelsior. Mechanical filters of both the gravity and pressure type are used, the former being used more extensively in the larger plants.

6. Sludge handling. In water softening a large amount of sludge is produced, the handling of which adds to the cost of operation. A number of methods for removing this sludge from the settling basins have been devised. In very large basins, after draining the sludge is discharged into a sewer by flushing with a hose and by hand scraping.

At Owensboro, Kentucky, the settling basins are fitted with a series of pipes resting on the bottom of the basins. This sludge removal system is divided into three sections in each tank, each

TABLE 5

Average results of analyses of raw and softened water, especially illustrating progression of softening—parts per million

SOURCE	TOTAL HARDNESS			
	A	B	C	D
Raw water	240	235	239	271
Outlet first basin	146	172	108	123
Outlet second basin	100	120	112	101
Outlet filters	83	104	99	86
Service mains	51	74	81	74

A—September 11, 1906.
B—January 15–18, 1907.
C—March 19–20, 1907.
D—August 20–21, 1907.

section being operated by a quick opening gate valve. The pipes extending across the basin are spaced about 3 feet apart and are perforated at 3-foot intervals. The tanks at Oberlin, Ohio, are also fitted with a socalled sludge removal system made up of 3-inch cast iron pipe, connecting to 6-inch cast iron main outlet pipes.

The manufactured softeners are fitted with a variety of devices for handling the sludge. At Hinsdale the device consists in a pipe set several inches above the bottom of the softening tank. This pipe is slotted along its under side. It can be revolved slowly so as to cover the entire tank bottom. At the top and center, it connects to an outlet pipe. The discharge is thus by the pressure of the overlying water as in sludge removal from an Imhoff tank. In other types, the bottom of the softening tank is built up of a large

number of small inverted cones, each connecting to a branch outlet pipe.

7. *Waste water.* The disposal of the waste water containing the sludge and the material washed from the filters is important. The lime salts in the sludge are apt to cause unsightly deposits in small streams. The volume of sludge is also comparatively large, which makes its disposal more difficult.

RESULTS IN PRACTICE

It is interesting to record a few of the benefits which have resulted to cities where water softening plants have been built. The following items are noted from a number of letters received from water works superintendents.

1. Soft water systems and double systems of plumbing no longer required.
2. Softening processes at the laundries discontinued.
3. Coal saved in water works pumping stations and in other power plants.
4. More palatable tea and coffee.
5. No stoppage of "stove backs."
6. Increased satisfaction with the water in domestic service.
7. Lower plumbing bills.
8. A large saving in soap.
9. Less trouble with boiler operation from scale formation.
10. A better water for ice making.

SUMMARY

1. As competition between municipalities for industrial establishments increases and as general water supply standards grow, the softening of municipal water supplies is likely to become a more general practice. This is particularly true in the middle west.

2. Hard waters have various characteristics and each water varies in quality from time to time, even when the water is drawn from a well.

3. As a whole, the chemistry of water softening is fairly complete, but there are still a number of undetermined points about which more information is desirable. Such, for instance, are the questions of foaming and of after-deposits.

4. There are now in operation a number of municipal water softening plants, from which a considerable experience is available. Careful design is required for each locality, with somewhat more liberal allowances in capacity than the manufactured softeners provide.

5. In many instances, even in small towns, the annual savings due to water softening will more than offset the cost.

In conclusion, the author wishes to acknowledge the kind assistance of Dr. Arthur Lederer, Mr. Robert A. Allton, and the various water works superintendents of the cities mentioned for information kindly sent to him.

DISCUSSION

MR. EDWARD BARTOW: In 1910 the speaker presented an article entitled "Water Softening for Municipalities" before the Indiana Water Supply Association. In the paper municipal water softening was advocated. It was stated that it could be done with slightly increased cost wherever it was necessary to filter a water supply to remove impurities; but that it would be a more expensive process to soften a well water which was hygienically pure and clear and does not require filtration.

The Hinsdale plant is the first plant constructed in Illinois, and it is to be hoped that it will be so successful that it will be a forerunner of other plants. Illinois waters are quite hard and there is a great field for water softening throughout the state.

An excellent example of saving by water softening has been brought to our attention. At the textile factory at Champaign, Illinois, the water was formerly softened by soap. The practice was to add 6 pounds of soap, costing 8 cents per pound to 250 gallons of water. The lime soap formed was removed by skimming and a bleaching mixture added to the water. When permutit softened water was used the 24 pounds of soap per 1000 gallons were saved and also 12 pounds less soap were needed for the bleaching mixture. The total saving in soap was, therefore, 36 pounds, or about $3 per 1000 gallons. Whether the water is softened by the zeolite or by the lime soda process the saving of soap is the same for each part per million of hardness removed.

RESANDING PROBLEMS AT ALBANY

By G. E. Willcomb

The scrubbers or rapid filters at Albany were placed in operation October 29, 1908. These filters are identical in construction with the socalled American mechanical filter except that they are designed to operate without preliminary coagulation, and in consequence are filled with a coarser sand than is customary to use in a mechanical filter. No air agitation during washing is provided for, dependence being upon a high vertical rise of the wash water to break up and carry off the schmutzdecke. The underdrain system is simple and consists of brass ferrules projecting one inch above the filter floor and spaced 9 inches on centers. Arranged radially around the perimeter are eight staggered holes each of which is $\frac{5}{32}$ inch in diameter. Twelve inches of gravel graduated from 3 inches to $\frac{1}{8}$ inch sizes was placed over the sand valves and 14 inches of sand placed over this. The sand used was disintegrated shale dredged from the bed of the Hudson River. Its effective size was 0.38 mm. with a uniformity coefficient of 3.17. Its cost in place in the bed was $1 per cubic yard.

Results of experimentation carried on over a period of a year demonstrated that under the above conditions a rate of 80,000,000 gallons per acre per day could be maintained giving an efficiency of 60 per cent in bacterial reduction and an efficiency of 50 per cent in the removal of turbidity. The experiments also showed that under such conditions the slow sand filters could operate at a maximum rate of 6,000,000 gallons per acre per day, which was twice the rate attained under the old conditions using water which had received 14 hours plain subsidence. During the experiments difficulty was encountered in washing the sand layer, the top 6 inches becoming silted up to such an extent that the wash water would divide it into sections, which being of a higher specific gravity would sink to the bottom, and soon form an impervious zone from the gravel to the top, such that the wash water could not make its way through the mass and took the course of least resistance around

it. A maximum vertical rise of 2 feet per minute failed to loosen up the sand, which resulted in the formation of springs over each sand valve, and ultimately decreased the bacterial efficiency in direct proportion as the resultant rate of filtration was increased through the restricted filter area. As a consequence, at the conclusion of the experiments it was realized that the sand in the actual filters would have to be ejected out of the beds and cleaned periodically.

The wisdom of employing a filter sand of such low effective size and with so high an uniformity coefficient was questioned at the time. To the writer its use was justified by the fact that it was the only cheap sand available at the time, and that by prolonged washing and scraping off of the fine sand brought to the top, an increase in the effective size would be attained, and as a consequence of prolonged washing the entire sand layer would be graded according to the hydraulic values of the separated sand grains, so that in the end, a graded filter medium would be worked up that would have filtering efficiency comparable to a sand medium of uniform sized grains from top to bottom.

The function of a filtering medium is to induce and maintain a schmutzdecke either of biological or chemical origin; all other functions are subordinate. Theoretically, a top layer 8 inches thick of 0.40 mm. sand ought to do as much useful work as 30 inches of uniform sand. If coagulation is employed and the coagulation is well executed, the top 8 inches will be as efficient in the removal of the residual hydrate as 30 inches of uniform sand. This fact is well illustrated by the conditions in the capital district about Albany, where there are four typical mechanical plants working under the same conditions as the Albany plant, yet all pass as much hydrate through the sand medium as does the latter plant. This serves to emphasize the fact that the phenomenon of the passage of hydrate through a filtering medium is a function of the degree of success of coagulation. Practically, the 8-inch layer does not work out as well as the uniform 30-inch medium. The efficiency of the wash is less and the tendency to ball and mound up is greater. In the case of the graduated sand, most of the silt and hydrate accumulated during the filter run is retained in the top 8 inches, consequently when the wash water is applied and the whole sand medium is in suspension and agitation, the tendency is for certain portions of the schmutzdecke layer to sink to a level of the fine gravel and become the nucleus of a ball or mound formation at that point. On

the other hand, the tendency of a graduated layer to pass fine particles of sand through the sand valves is much less than with a uniform sand. The writer's experience with different mechanical plants has impressed him with the importance of this fact, and in the light of all things considered, it is his opinion that the increased initial cost of a uniform sand is not justified by the increased benefits derived.

As was stated at the beginning, the rapid filters were started October 29, 1908, with a 14-inch layer of sand of an effective size of 0.38 mm. After fourteen washings samples of sand were taken at different depths and table 1 gives the results of the mechanical analyses:

TABLE 1

SECTION	EFFECTIVE SIZE	UNIFORMITY COEFFICIENT
inches		
0– 2	0.31	1.29
2– 4	0.31	1.51
4– 6	0.32	1.72
6– 8	0.32	1.88
8–10	0.38	2.00
10–12	0.39	2.56

After three weeks of operation 4 inches of fine sand were scraped off the top and the condition of the remaining sand is shown by the following table:

TABLE 2

SECTION	EFFECTIVE SIZE	UNIFORMITY COEFFICIENT
inches		
Top 4	0.45	1.78
4– 6	0.41	1.95
6– 8	0.46	2.15
8–10	0.53	2.45

From table 2 it is seen that a 10-inch layer of sand had been worked out of the 14-inch layer, the top 8 inches of which was fairly uniform and whose effective size seemed quite favorable. After using this sand for two months, it became rapidly silted up down to the gravel and had to be forked at frequent intervals as a supplement to the wash.

On June 22, 1909, eight months after the rapid filters were placed in operation, all of the Hudson River shale sand was ejected out of the beds and 30 inches of fresh shale sand from the same source put in its place. After a series of washings of the sand in place in the beds, and after several shallow scrapings had been removed, the resultant filter medium had the following composition:

TABLE 3

SECTION	EFFECTIVE SIZE	UNIFORMITY COEFFICIENT
inches		
0– 6	0.42	1.91
6–12	0.45	2.10
12–18	0.50	2.24
18–24	0.51	2.94

The beds were operated with this sand until October 24, 1912, a period of three years and four months. During this time the sand was ejected, cleaned and replaced five times. On each ejection approximately 3 per cent of fine sand was lost and owing to the shaley character of the sand a large percentage of the grains became disintegrated by erosion and the top portion of the bed became finer in consequence and the tendency of the filter to ball up increased.

It was decided at this time to replace all the shale sand by silica sand and quotations were asked both for a graded and ungraded product. It was found that the cheapest graded sand that could be procured came from Cape May, New Jersey, and would cost $3.75 per ton f.o.b. Albany. Ungraded silica sand could be brought from Hemstead Harbor, Long Island, in scows for $0.95 per cubic yard. Owing to the great difference in price, it was decided to use this latter sand and work it over in the beds until it was suitable for the purpose. Samples taken from the scows showed the sand to have an effective size of 0.25 mm. with an uniformity coefficient of 2.28.

During October 1912, all the old shale sand was discarded and 100 cubic yards of the new silica sand placed in each bed. At different periods varying amounts of fine sand were scraped off the top and table 4 shows the results obtained by the scraping:

TABLE 4

TIME ELAPSED SINCE FILLING BED	TIME ELAPSED SINCE LAST SCRAPING	AMOUNT SCRAPED	SUM TOTAL OF SCRAPINGS	RESULTANT EFFECTIVE SIZE OF ENTIRE SAND	RESULTANT UNIFORMITY COEFFICIENT
days	*days*	*inches*	*inches*		
14		4	4	0.33	1.79
21	7	4	8	0.38	1.84
28	7	4	12	0.43	2.11
35	7	3	15	0.45	2.44

From table 4 it is seen that by prolonged washes and successive scrapings a sand of an effective size of 0.45 mm. was worked up out of the 0.25 mm. sand at the expense of rejecting 37½ per cent of the fine material. Experience has shown that had the time interval been longer and shallower scrapings made, this percentage loss would have been much less. It is seen that upon each successive scraping the uniformity coefficient increased in proportion. The higher the coefficient the more stratified did the total filtering medium become.

In order to demonstrate the degree of stratification of the filtering medium, mechanical analyses were made on different sections of the sand taken at different depths. Each determination represents the average obtained from several samples. In order to demonstrate the efficiency of the wash, six samples representing total sections of the bed from top to bottom of about 30 inches in depth, were analyzed for turbidity, organic nitrogen and oxygen consumed. The method employed was as follows: 100 grams of the sand were shaken in the engine with 100 cc. of water for one minute after which it was diluted to 1 liter. This liquid containing the schmutzdecke released from the sand by agitation was used as the base solution in making the determinations. In making the organic nitrogen determination, a modification of the Kjeldahl method was employed using phosphoric anhydride and direct nesslerization to facilitate matters. Corrections were made for moisture and the results expressed as parts per 10,000 grams of dry sand.

Table 5 gives the effective size of the different sections, the amounts of the different constituents stored in the total section of the filter medium, at six different points in the bed before and after the wash, and the percentage reduction of these constituents due to the wash.

TABLE 5

SECTION	EFFECTIVE SIZE	UNIFORMITY COEFFICIENT	Station	EFFICIENCY OF WASHING: Before washing: Turbidity	Before washing: Organic nitrogen	Before washing: Oxygen consumed	After washing: Turbidity	After washing: Organic nitrogen	After washing: Oxygen consumed	Per cent reduction: Turbidity	Per cent reduction: Organic nitrogen	Per cent reduction: Oxygen consumed
inches												
0- 4	0.34	1.38	A	1400	1.00	9.8	975	0.68	6.8	30.4	32.0	30.6
4- 8	0.34	1.82	B	1400	0.96	8.5	875	0.64	7.0	37.4	33.4	17.7
8-12	0.62	1.77	C	1400	1.00	9.0	900	0.60	6.5	35.7	40.0	27.7
12-16	0.62	1.72	D	1500	0.80	10.6	925	0.36	7.0	38.3	54.9	34.0
16-20	0.64	1.72	E	1300	0.60	9.1	900	0.40	6.6	30.8	33.3	27.5
20-28	0.54	1.80	F	1750	0.80	9.9	1200	0.92	4.2	31.4		57.6
28-36	0.60	1.70										
Average				1460	0.86	9.5	965	0.60	6.4	33.9	32.2	32.6

TABLE 6

SECTION	BEFORE WASHING: Effective size	Uniformity coefficient	Turbidity	Organic nitrogen	Oxygen consumed	SECTION	AFTER WASHING: Turbidity	Organic nitrogen	Oxygen consumed
inches						*inches*			
A 0-10	0.35	2.08	1750	1.60	16.5	Av. (A+B) 0-10	1600	1.80	17.3
B 0-10	0.33	2.24	1750	2.20	19.7	Av. (C+D) 0-10	1500	1.60	15.1
C 0-10	0.38	1.95	1800	2.00	18.7				
D 0-10	0.37	1.67	1600	1.60	15.3	Average	1550	1.70	16.2
Average	0.36		1725	1.90	17.5	Av. (A+B) 10-20	1400	0.96	14.5
						Av. (C+D) 10-20	1400	0.90	8.4
A 10-20	0.36	2.37	1750	1.44	15.7				
B 10-20	0.42	2.38	1400	0.96	15.5	Average	1400	0.96	11.4
C 10-20	0.38	2.23	1500	1.04	14.1				
D 10-20	0.50	2.80	1200	0.88	9.0	Av. (A+B) 20-30	1350	0.24	13.7
						Av. (C+D) 20-30	1250	0.64	9.9
Average	0.40		1450	1.08	13.6	Average	1300	0.45	11.8
A 20-30	0.54	2.77	1200	0.64	12.3				
B 20-30	0.49	3.26	1250	0.24	12.5	AVERAGE PERCENTAGE REDUCTION			
C 20-30	0.40	3.00	1400	0.72	11.7				
D 20-30	0.52	3.07	1400	0.80	9.5	0-10	10.2	10.5	7.4
						10-20	3.6	11.1	16.2
Average	0.49		1300	0.60	14.0	20-30		25.1	15.7

It is seen from table 5 that, as might be expected, different portions of the bed store up more matter than others. A point of interest is the fact that the percentage reduction of all constituents is about the same. It must be noted that at the time these tests were made, the beds were being used as scrubbers and this accounts for the low percentage removal of stored turbidity, etc. It is therefore evident that the action of a scrubber is more or less accumulative; that the silt and organic matter, etc., are gradually stored up in the sand and eventually must be removed by ejection.

In order to ascertain the efficiency of the washing process at different depths of the bed, samples of 10 inch depth were taken at various portions of the filter. Table 6 gives the results obtained.

It will be observed that the efficiency of the wash in this instance is much less than that shown in the case of the preceding table. This may be explained by the fact that in the preceding instance the test was run during the winter while the latter was run in the summer time, when the organic growths were at their maximum development and their resistance to the agitation of the wash was greater. It is seen that as the effective size increases, the amount of matter stored up in the sand voids is correspondingly less. The efficiency of the wash in each stratum of the bed is practically the same.

In conclusion it may be said that out of a sand costing $0.95 a cubic yard, a sand of an effective size of 0.45 mm. was worked up by rejecting 37.5 per cent of the material by successive scrapings. Including the cartage this final sand cost $1.55 per cubic yard which was $2.83 a yard less than a uniform sand could be placed for. This cost does not take into account the pay of the laborers on the regular payroll, who did the work of washing the sand. Had extra labor been employed to do this work the cost of the final sand in place would have been increased by about $.15 per cubic yard.

SITUATION AT LITTLE FALLS, NEW JERSEY

By F. W. Green

The difficulties that arise at any given filtration works depend upon the character of the natural water to be treated, both as to its mineral and organic constituents. The Passaic River at Little Falls, New Jersey, is a rather highly colored surface water, comparatively free from contamination and of medium hardness for this section. It presents the usual problems of a water of this class: namely, intermittent occurrences of red water troubles, difficulty of coagulation and low organic matter after filtration. This latter in turns means delicacy of chlorine reaction.

Fortunately, these conditions are by no means continuous and therefore the filters can generally turn out a product that is perfectly satisfactory in every respect. The aim is to maintain the output at the highest degree of perfection at all times, from an esthetic as well as a hygienic standpoint, and the author wishes to present to you some of the more recent developments for this purpose that have been tried, or are about to be tried at the Little Falls plant.

The first subject for consideration will be red water. There are several theories to account for the phenomenon called red water. At present the experiments at Little Falls are based on the free carbonic acid theory. The writer wishes to advance the theory that free carbonic acid may exist in the water in two conditions; not only may there be free carbonic acid existing in a water supply in the dissolved state, but also in what may be called the entrained state. The quantity of free carbonic acid which water can dissolve depends upon both the temperature of the water and the pressure to which it is subjected. At atmospheric pressure, and a temperature slightly above freezing, water can absorb about fifteen parts per million of free carbonic acid. During the colder months of the year water of this temperature is often handled that is saturated or nearly so with free carbonic acid. When, on passing through the pump, such a water is subjected to a greatly increased pressure, it be-

comes supersaturated as regards the carbonic acid content, and the excess exists, as small bubbles of the gas, in what has been termed by the author the entrained state. An increase in the temperature of the water merely exaggerates the case, so that red water is most frequently a hot water trouble.

The present method of attack at Little Falls is the addition of lime by means of two helicoid conveyors, and also a system of electrolizing the water by means of a low density current is being worked out, the gas being gathered as bubbles on a specially designed cathode, and then removed by a process which will be patented when perfected, and therefore can not be given in detail at present. In both cases only sufficient carbonic acid will be removed to leave a residual content of say ten parts per million.

Difficulty of coagulation occurs at widely separated intervals, and gives rise to flocculant hydrate in the effluent. At times it requires a considerable period of time after filtration for these flocs to gather, and the writer feels confident that in many of the smaller plants their presence would be noted much more frequently were it not for the fact that the water has been consumed before there has been time for them to settle out.

The first experience of hydrate in the effluent occurred in 1902, soon after the plant was put into operation, and it is still occasionally encountered. At times a heavy floc occurs in our sedimentation basin, but it is so delicate in construction that it is entirely broken up before it reaches the filter beds. It is hoped that our new 5,000,000-gallon coagulation basin will enable us to become better acquainted with the causes that lead to this condition. This problem is more or less intimately connected with abnormal conditions of the "oxygen consumed" content.

The "oxygen consumed" content has undergone violent fluctuation at all the plants in the vicinity during the past two years, due to crude oil (fuel oil) treatment by the Mosquito Extermination Commission of the ditches and pools of the meadows and other low lying parts of the watershed. All stagnate water has been coated with a film of fuel oil in order to prevent the growth of the incipient mosquito. After a rain the oil is washed over the meadows, thereby killing the grass or hay and extracting its coloring and other organic properties and leaving the grass dead and brittle, and bleached to a grayish white. The amount of color in the water has been higher this past year than ever before, and the shade of the water

was a brownish tan, entirely different from any normal water. Later on the action causes low "oxygen consumed" and difficulty of coagulation, or rather fragility of the aluminum hydrate floc.

Low oxygen consumed also necessitates greater care in the application of the sterilizing agent. Under normal conditions any slight excess of chlorine is taken care of by the organic matter that is present in the water, but when the oxygen consumed is low, extreme care is required to introduce a quantity of the sterilizing agent sufficient to eliminate the B. coli and practically all of the harmless bacteria, and at the same time steer clear of the tastes or odors due to overdosage. While realizing that sodium thiosulphate will absorb the excess of chlorine that may be added under these circumstances there is extreme reluctance about applying an additional chemical.

In conclusion the writer wishes to call particular attention to the present status of the method by which the sterilizing agent is introduced into the water. At most plants where an agent is applied chlorine is used in one or the other of two forms. This chemical was first used in the form of bleach, and it was gladly welcomed, for the reduction of coagulant and the marvelous residual bacterial content which it made possible, far outweighed its unpleasant features. Then came liquid chlorine to relieve many of these disagreeable features. The chlorine was confined in a strong steel cylinder. The contents were all chlorine and went directly from the tank through the regulating apparatus and the absorption device into the supply, but it is more expensive. There is at times, many hours' supply ready and anxious to escape into the water, and even a 10 per cent additional dose would be very undesirable. A thin diaphragm is depended upon to prevent such a calamity; also there have been times, even at plants where the average amount of intelligence has been bestowed upon the handling of the chlorine, when a cylinder of liquid chlorine has been known to escape into the atmosphere with unpleasant results. The writer does not speak from personal experience, but does not feel assured of safety from a similar experience, in spite of oft repeated warnings on his part, upon the subject. Slight leaks are of frequent occurrence, and a certain amount of the chlorine is necessarily liberated each time an empty cylinder is disconnected from the measuring apparatus.

The reason for having had to use either the bleach or liquid chlorine is purely one of transportation. Chlorine under normal

conditions is a gas, and has been manufactured at a point distant from its place of application. In order to transport it, it was necessary to absorb it by means of some suitable medium, and from a commercial standpoint lime was the most satisfactory material to use. By passing the gas over lime, bleach, or bleaching powder, is secured, but this is a rather unstable product that is made up of a mixture of calcium chloride and calcium hypochlorite. It is strongly deliquescent, and after absorbing water attacks iron, of which most of our domestic containers are made, very actively. Finally, half of the chlorine is combined so securely that it is no longer available and so it is lost forever. Bleach has been added as a milk, in which case the solution tanks should be constantly stirred, or the solution has been allowed to settle and only the supernatent fluid drawn off for use; each system has its drawbacks, but it is the cheaper and safer method.

Liquid chlorine is much nicer to handle when everything goes well, as it usually does, but it is somewhat more expensive. The cost of manufacturing the chlorine gas is reasonable enough but to prepare it for shipment it must be purified, dried and liquefied. If made by the hot process cell it must be cooled before this is done, and it must be compressed to a liquid with further cooling. The containers in which it is shipped must conform to very strict rules as specified by the government, and the valves and the caps of the cylinders must be very carefully gone over each time they are returned to the factory. All of this adds to the expense, and when a sudden foreign demand occurs to drain the country of both the gas and containers, which are left on the battle field, the price soars still higher.

The answer to these problems appears to be for the larger filtration works to purchase their chlorine as common salt, sodium chloride, and manufacture their own chlorine gas by the process in use at the factories. Rock salt is worth in New York City less than $5 a ton, and a ton will supply a 20,000,000 gallon per day plant for a month. The gas could be taken directly from the electrolytic battery and applied to the supply. The cold process cell could be used and all the drying, cooling, purifying, compressing and transporting charges would be eliminated.

Small plants should use bleach, liberating both the available and unavailable chlorine by means of crude sulphuric acid, and applying same as a gas. This has been done by the writer in the labora-

tory and appears to be the ideal way. Combined with suitable containers, say of earthenware or glass, for the storage of the bleach, it is a far superior process to the present crude method. At present it would appear that works handling 5,000,000 gallons of water a day should install their own chlorine factories and those smaller than this should release the Cl from the bleach and apply it as a gas; in both cases getting it in a nascent state and using it in the most advantageous, safe and agreeable manner.

DISCUSSION

MR. GEORGE A. JOHNSON: Mr. Green's closing remarks in reference to hypochlorite of soda manufactured on the ground recall to the speaker some very interesting facts which were considered long ago. If, when bleaching powder first came into use, as much had been known about the electrolytically produced hypochlorite as is now known, bleaching powder would have had a hard time getting the hold it has.

The process of making hypochlorite of soda electrolytically is a simple one, and where electric current costs about 1 cent per kilowatt hour, and where common salt may be had for $\frac{1}{4}$ cent per pound, hypochlorite may be produced for practically the same price as bleaching powder costs when the market is normal, basing such costs on a unit of available chlorine.

It will be of interest if Mr. Green will tell us if, with the use of the large quantities of fuel oil on the watershed, for the extermination of mosquitoes, trouble has ever been experienced from tastes produced by the oil so used.

MR. F. W. GREEN: There is a slight oil scum on the water once in a while. This oil is put in the ditches below the surface of the surrounding meadows and lies there without doing harm until a rainstorm comes. Then a part of it appears to attack the grass and vegetable matter and part of it comes down as a scum. It is all taken out and left in the filters, but more or less trouble from clogging of the filters is anticipated.

With the chlorine process we have investigated both the manufacture of sodium hypochlorite and chlorine as a gas, and find the latter is much better to use and less liable to cause tastes and odors. There is nothing added to the water except the chlorine, which is the part that is desired.

THE DEVELOPMENT OF RAPID SAND FILTERS IN OHIO[1]

By Philip Burgess

The early installations of municipal water works plants in Ohio generally were the results of requirements for fire protection, and but little attention was then given to the quality of the public water supply obtained. Within recent years, however, the rapid increase in population has caused appreciable and in some cases serious pollution of all surface waters in the state; and at the same time, there has been brought about by a campaign of education a much larger and fuller appreciation of the value and worth of a pure public water supply. Experience indicates that the rapid sand filter is best qualified for the purification of the comparatively turbid waters found in the Middle West, and it is the writer's endeavor to indicate what a prominent and important part in the development of the history and art of water purification by rapid sand filters has been played in the state of Ohio.

Possibly a few general remarks, relative to the growth and character of rapid sand filter plants in Ohio, will indicate how true this is. In this connection, it may be noted that a patent for the use of a coagulant in connection with the filtration of water was granted to J. L. Hyatt in 1884. In view of the fact that a satisfactory treatment of water by rapid sand filters requires the application of a coagulant, the beginning of the development of rapid sand filter plants for the treatment of municipal water supplies naturally followed the above date, and the first of such plants was constructed in the United States at Sommerville, New Jersey, in 1885. Of course, during the early history of the art, there was no assurance to the public that a rapid sand filter plant would produce satisfactory results and would render municipal water supplies of satisfactory quality for domestic use, so that nearly all such early municipal filter plants were constructed under guarantees of efficiency of results to be accomplished.

[1] Read at Central States Section Meeting.

The first rapid sand filter plant in the United States provided for the purification of a municipal water supply, and constructed under a guarantee of efficiency was contracted for by the city of Lorain, Ohio, in May 1896. The first rapid sand filter plant constructed in the state of Ohio was built at Warren in 1895. The first municipal water softening plant constructed in the United States was built at Oberlin, Ohio, in 1903, and rapid sand filters of the pressure type were used to filter the softened water. The largest municipal water softening plant in the world and the second largest rapid sand filter plant in the world are constructed at Cleveland, Ohio, and have a capacity of 144,000,000 gallons daily. The third largest rapid sand filter plant in the world also is in Ohio, at Cincinnati, and has a capacity of 112,000,000 gallons daily. Moreover, the Cincinnati filters were the first muncipal filters designed for the application of wash water at high rates without any other means of agitation for cleaning the sand. In building the Cincinnati filters, a brass wire screen was placed over the gravel to keep it in place during washing. The first municipal rapid sand filter plant designed for high rates of washing, and constructed with deep, coarse, gravel layers over the strainer systems without superimposed screens for holding down the gravel during washing was constructed at Niles, Ohio, in 1910.

The first filter plant at which alum has been manufactured for use as a coagulant is at Columbus, Ohio.

The first municipal rapid sand filter plant at which the disinfectant qualities of common lime have been intelligently and knowingly utilized is at Cleveland, Ohio.

The first systematic investigation by a state board to determine the efficiencies of the filtration plants in a state was made by the Ohio State Board of Health in the years 1906–8.

Just as it is true, as indicated above, that the state of Ohio has done more to develop the art of rapid sand water purification than any other state, so is it true that the citizens of the state are now enjoying the use of larger rapid sand filter capacities than any other state. This is well indicated in the following table wherein are shown the filter capacities and the population served by rapid sand filters constructed in Ohio during the several periods indicated.

Table showing progress in construction of rapid sand filter plants in Ohio

PERIOD	POPULATION SERVED BY NEW PLANTS AT END OF PERIOD	DAILY CAPACITY OF NEW PLANTS (GALLONS)
1895	7,900	1,450,000
1896–1900	35,371	7,870,000
1901–1905	123,284	24,520,000
1906–1910	777,293	179,650,000
1911–1915	930,674	236,200,000
Total present daily filter capacity ..		449,200,000
Total population served in 1915.....	1,940,000	

Table showing percentage of population of state of Ohio served by rapid sand filters

YEAR	TOTAL POPULATION OF STATE	POPULATION SERVED	PER CENT
1900	4,157,545	43,900	1.1
1905	4,462,333	185,486	4.2
1910	4,767,121	945,819	20.7
1915	5,071,909	1,940,000	38.3

From the above tables it is shown that the first rapid sand filter plant was constructed in 1895 and had a capacity of 1,500,000 gallons daily. It served a population of 7900. At the present time the total filtering capacity of rapid sand filter plants now in operation or under construction in the state of Ohio is 450,000,000 gallons daily and the filters serve a population of nearly two millions. It is of interest to note that the total nominal capacity of filters now in operation or under construction in the state is sufficient to provide nearly 90 gallons of filtered water daily for every resident in the state.

Possibly the most interesting feature in connection with the construction of rapid sand filter plants in Ohio is the development which has been accomplished in the design and construction of the plants. As would be expected in the interval of time that has elapsed from the construction of the first plants to the present time, there has been a marked improvement in the design and arrangement of the units especially in regard to the treatment of the water before it is passed through the sand filters, and in regard to the size, form and construction of the filter tanks.

As previously stated, the first plant constructed in Ohio is of the Warren type and consists of units containing sand filtering beds supported on perforated metal plates. Beneath the filter bed bottom of each unit is a chamber into which the filtered water pours on its way to the main filtered water outlet. During washing water is turned under pressure into the clear water compartment beneath the sand and forced upward through the perforated plates and into the sand. Such a strainer system may be classed as an "open type strainer." The disadvantage of such a system is that it is difficult to get a uniform distribution of wash water throughout the entire area, especially in large units. The design is satisfactory for small units, but it is not entirely satisfactory for larger units on account of its excessive expense and because of the difficulty of obtaining a uniform distribution of the wash water over the filter bottoms, as they were originally constructed. This was especially true in the old units wherein the sand was supported on brass wire screens, having comparatively large aggregate openings.

The filters constructed at Lorain were of the Jewell type. The essential features of these filters were that the strainer systems were composed of perforated pipes containing sand valves placed at uniform intervals covering the filter bottom. Filtered water was collected in the strainer pipes and carried to a main storage reservoir. No filtered water compartment for collecting the effluent was provided beneath the sand. It is significant that many modern plants still are constructed using strainer systems of this type.

The advantage of this system is that the wash water can be applied at higher rates under greater pressure without danger of damaging the filters. Moreover, the design permits the construction of a second compartment beneath the filter to store the water for sedimentation and coagulation on its way to the filter. The disadvantage of this strainer system, which is of the "closed type" is that it sometimes clogs by growths or other foreign matter and that there is then considerable difficulty in properly cleaning the strainer systems.

A modification of this closed type of strainer is to be found in the Hyatt cone valves, such as are used in the filters at Geneva and Newark, Ohio. These valves comprise castiron cones about 6 inches high and 6 inches in diameter at the top, covered with brass, perforated hemispherical plates, and containing shot or fine gravel.

The principal advantage of these units is that they can be taken apart and cleaned without damaging the strainer system.

As shown above, the old Warren type filters contained no provision whatever for treating the water before it was applied to the filters, so that the only opportunity permitted for coagulation and sedimentation was as the water stood above the sand in the filters or by providing outside settling tanks. The period of coagulation provided in the filters was about fifteen minutes. Approximately the same period of time for coagulation was permitted in the compartment provided beneath the Jewell type of filters at Lorain.

Probably the greatest development in the art of water purification has been an appreciation of the fact that the burden to be placed upon the filters should be made as small as possible in order to accomplish the most satisfactory results at the least expense. Within reasonable limits, it is true that the percentage removal of bacteria and other impurities by the filters themselves is limited, so that, of course, the best results are accomplished by removing all possible impurities by preliminary treatment before filtration. This has been appreciated in the design of modern plants wherein the period provided for coagulation and sedimentation previous to filtration is frequently from three to six hours.

In the same way, there has been a marked development in the design of the filter tanks themselves. The phrase "mechanical filter," frequently applied to rapid sand filters, was derived from the fact that a stirring device, or mechanical agitator, was provided to stir the sand in the filters and thus to assist in the removal of impurities during washing. It is obvious that such a device required a circular filter tank. As early as 1889, it was recognized that air under pressure could be used to agitate the filter sand during washing and the application of this principle, of course, permitted the use of rectangular tanks in place of the circular tanks as previously required with mechanical agitators or rakes. This principle has proven of great value in reducing the construction cost of the larger mechanical or rapid sand filters, because it has permitted the use of reinforced concrete rectangular units occupying very much less area than is required for circular tanks of the same capacity.

It is significant of the development of the art of water purification that the last wooden tank filters now operating in Ohio, and provided with mechanical agitators, very soon will be removed and replaced by rectangular concrete tanks. The old filter plant at

Lorain was replaced some years ago by a modern concrete filter plant, and it is of interest to note that the results accomplished by the modern plant today are no more satisfactory than the results which were accomplished by the old plant, before its capacity was exceeded. Moreover, the cost of operation of the new plant is considerably in excess of that of the old plant.

In view of the disadvantages apparent in the closed type of strainer system comprising perforated pipes equipped with sand screens, or valves, engineers have endeavored to develop a strainer system of the closed type in which all parts would be accessible. The first strainer system to be developed along these lines in Ohio was used at Cincinnati, and comprised lateral concrete channels covered with perforated brass plates. The design permits the removal of the plates, and inspection and cleaning of all parts of the strainer system. Owing to construction imperfections, especially at the shoulders where the brass plates are supported, some engineers have reverted to the original form of closed or pipe strainer system. Possibly this action has been taken, in part, because of patents covering the use of depressed channels in filter bottoms.

A further important modification in the design of rapid sand filters was developed at Cincinnati and comprised the use of wash water without either air or mechanical agitation for cleaning the sand. Experiments conducted by Mr. J. W. Ellms indicated that when the wash water was applied at rates greater than 18 inches vertical rise per minute the entire sand body was thoroughly agitated and moved by the wash water, so that further agitation by mechanical means or by air under pressure was not required. It was thought at that time that the high velocity of the incoming wash water would require that the filter gravel, placed above the strainer system, be restrained in place by brass screens. Subsequent developments, however, have shown that the screens are unnecessary and during the past two years they have been removed and the gravel layers deepened.

This fact was appreciated in the design of the rapid sand filter plant constructed at Niles, in 1910, under the direction of the writer, where wash water is applied at a rate of about 24 inches per minute without any disturbance of the filter gravel which consists of coarse, deep layers not fastened down by screens.

In this connection it may be noted that not the least important development in the design of rapid sand filters has been in connec-

tion with the use of larger and deeper gravel layers. In the old Warren and Jewell type filters, such as were built at Warren and Lorain, Ohio, no gravel whatever was placed between the strainer systems and filter sand. This method of construction in fact was continued for a number of years, and until 1910 some filter plants were constructed without any filter gravel. The writer has known instances where the construction of old filters has been modified by placing gravel above the strainers with the result that much more efficient washing of the filters has been accomplished by the use of very much less wash water. It is undoubtedly true that the gravel layers play an important part in distributing the wash water throughout the filter area, as well as in keeping the sand from passing through the strainer system, so that the successful washing of filters, especially under high rates, may be largely attributed to the use of coarse, deep, gravel layers.

A considerable part of the expense of operating a rapid sand filter plant is incurred by the cost of the necessary coagulant, and any development which tends to reduce the cost of the chemical is, of course, an important advance in the art of water purification. The coagulant most commonly used is filter alum, or aluminum sulphate, which generally is purchased in crystalline form at a cost of about 9 cents per pound.

At the Columbus, Ohio, Softening and Rapid Sand Filter Plant, filter alum is manufactured directly at the plant. The alum manufactured at the Columbus plant is not filtered or crystallized but is applied in the crude liquid form. It is obtained at less than one-half the cost of the finished manufactured product, and, on account of the fine clay contained in the liquid, has proven even more efficient than the clear crystallized chemical.

Another notable development in the art of water purification has been accomplished by the introduction of disinfectants or sterilizing agents. The three disinfecting agents which have been used on a large scale to disinfect municipal water supplies are hypochlorite of lime, liquid chlorine and quicklime, or calcium oxide, and the use of these germicides has become so universal that it is the exception where a filter plant effluent is not treated in this manner. The most common treatment is with hypochlorite of lime, or with liquid chlorine gas.

The municipal softening plant at Columbus, Ohio, has offered unusual opportunities to study the germicidal effect of quicklime,

which is used primarily to soften the hard water of the Scioto River, but which is found also to destroy bacterial life in the treated water by eliminating the carbonic acid which appears to be necessary for sustaining such life. Dr. A. C. Houston, Chemist of the Metropolitan Water Board of London, England, probably is the first observer to note such germicidal action of lime. He recommended the application of lime to river water in excess of the amount required to soften the water, thus causing a caustic alkalinity of the treated water, a feature which he considered to be necessary to obtain any sterilizing action by lime treatment.

In a recent engineering magazine, is an article by Mr. Hoover, chemist in charge of the Water Purification Works at Columbus, Ohio, showing the results of his experiences and experiments on the germicidal action of lime. Mr. Hoover's conclusions, as stated in the article, are thought to be of general interest,and are as follows:

CONCLUSIONS BASED ON EXPERIMENTS

1. When enough lime is added to water to absorb the free and half bound carbonic acid and to precipitate the magnesium content, the bacteria of the colon and typhoid group are killed in forty-eight hours after being so treated, provided the water does not contain large quantities of organic matter.
2. The germicidal action is effective in from five to twenty-four hours when an excess of 0.5 to 1 grain per gallon is added beyond that needed to reduce the temporary hardness to the lowest possible figure.
3. The intestinal organisms will not live in water containing no free or half bound carbonic acid.
4. Lime softened water inoculated with typhoid organisms or with crude sewage soon becomes free from them.
5. The action is selective in that certain harmless bacteria grow but the disease producing germs do not.

The sterilizing action persists indefinitely.

In a recent paper on water disinfection by chemical methods Mr. Samuel Rideal states the advantages of using chemicals that persist in their disinfecting action in the following words:

It is at the same time a disadvantage, if a disinfectant however powerful in its first onset, is very evanescent, as many disease germs are strongly resistant and we know that the time factor is of extreme importance in sterilization.

It is apparent that quicklime has a great advantage over hypochlorite of lime or liquid chlorine as a germicide, because its action

continues indefinitely so long as the lime treated water contains no carbonic acid, whereas, on the contrary, the germicidal action of the hypochlorite continues but a short time after the application of the chemical.

The germicidal action of quicklime, together with the appreciation of the value of softened water, have been utilized in the design and construction of the new water purification plant of the rapid sand filter type recently constructed for the city of Cleveland, Ohio. The use of lime to treat and soften Lake Erie water, which has an average total hardness of not more than 115 parts per million, is a radical departure from former current practice, because such water, especially in the Middle West where hard waters prevail, would be considered of satisfactory quality for domestic use without softening. It is reasoned, however, that owing to the considerable difference in cost per ton of quicklime and of alum, it is possible to use about four times as much lime as alum at the same expense. The lime, however, has a continued germicidal action, especially on intestinal bacteria contained in the water, and moreover, the lime will soften the supply, which will thus be made more desirable, at but slightly more expense than would be entailed by the usual methods of filtration, using a coagulant such as filter alum.

It is, of course, difficult to state where further developments in the art of water purification may be accomplished, but it is very apparent that the present stage of development is such that it is possible to treat even a badly polluted river water by rapid sand filters, and in conjunction with a sterilizing process, to produce a water very satisfactory in all respects for domestic use. It has been the purpose of this paper to call to the attention of the members of this Association how prominent a part has been and is being played in Ohio in the development of the art of purifying surface waters by rapid sand filters, because it is doubtful if the members appreciate the fact that in this state are to be found plants which represent practically all stages of advance in the design and construction of rapid sand filters. Moreover, such Ohio cities as have to solve the problem of obtaining a public water supply of good quality from a polluted surface water can approach the matter with entire assurance of its satisfactory solution by the introduction of a rapid sand filter plant either with, or without, some germicidal treatment as circumstances may require.

SOURCES OF WATER POLLUTION[1]

By John W. Hill

From personal experience the writer came to a realization of some of the difficulties in obtaining satisfactory sources of water supply for many of the smaller and some of the larger cities and towns in the state. There are many settlements in Ohio which have grown into populous villages and cities by reason of local conditions which have affected their prosperity, and when they have reached the size and dignity of a large village, or a small city, and sought to obtain the usual sanitary conveniences now considered as essentials of populated centers, have found that there was no convenient source of public water supply, or convenient and safe point of disposal for sewage, both of which are essential to the life and growth of any considerable village or city today. Other problems with respect to the disposal of city wastes also arise as villages and cities grow in numbers and density of population; but the chief and first problems are an adequate and safe water supply, and a convenient and safe method of disposing of village and city sewage.

The sources of public water supply in this state are low level lakes, like Lake Erie, rivers, creeks, wells and impounded water. There are a few small natural lakes at high elevation in the state, from which water can be drawn by gravity; but with no exception can such water be considered wholesome and safe for drinking purposes in its natural condition.

Water from Lake Erie, the Ohio River, or any other river or creek in the state, cannot be used in safety to health without some artificial purification. This fact is recognized now, although it was not a few years ago. There may be some spots in Lake Erie, far removed from its shores, where the water is safe for domestic purposes, but these spots are not within practicable reach, and may not at all times be safe. The lake is shallow and simply a wide stream for the discharge of all the polluted water that reaches it from the other three Great Lakes and numerous sewage polluted rivers and

[1] Read at meeting of Central States Section.

creeks which discharge into it. In addition to the sewage from municipalities and other land sources which reaches the lake, there is the constant discharge of sewage from the vessels which traverse it. So that if there are sources in the lake from which a safe water supply can be drawn today, there can be no assurance that the source will be safe tomorrow.

Safety is here meant to apply to water for drinking and domestic uses, and not to water for commercial purposes, or for flushing sanitary appliances. Water for the bath and the lavatory should be free from infectious organisms, if it is to be used without risk to health.

Driven wells, if the yield of water is sufficient, are generally regarded as our best sources of public water supply in this part of the country, but care must be exercised that the naturally pure water at the bottom of a driven well is not polluted and cannot become polluted by organic and perhaps infectious matter from surface and ground sources.

A short time since there came under the writer's observation the case of a water supply from driven wells which furnished some new and interesting information. A tube well had been driven to a depth of 120 feet, tested for capacity, found to yield a satisfactory volume of water, and samples of the water when analyzed were in all respects excellent. A second well located 250 feet distant, driven to the same depth, through the same strata, into the same water bearing sand, when tested for water quality was found to be of about the same chemical and physical character as the water from the first well, but contained in all samples abundant colon bacilli and showed decided sewage pollution.

The first well was satisfactory as a source of domestic water supply, the second well was not, and yet from all outward appearances there was no reason why there should have been any difference between the sanitary analyses of samples of water from the two wells 250 feet apart and driven into the same water bearing strata. There was a difference, however, the cause of which was not discovered by the state board of health. The first well when tested was pumped to a point of discharge where it flowed away in surface channels, which were not in connection with the water bearing strata from which the water was drawn, and the test samples collected from the unpolluted source 120 feet below ground level. The water from the second well upon pumping for yield was discharged into

an abandoned and forgotten privy vault, about 12 feet from the well, not known to the officials in charge of the work, and from this vault, or cesspool, the colon bacillus was carried through the porous strata to the drive pipe of the well and mixed with the water from the strata which furnished the well supply, and came to the surface by pumping, and was found in the test samples of water taken for analysis.

There was thus established a circulation of water, from the unpolluted source to the abandoned vault, and from the vault through the porous earth and drift materials to the strainer at the bottom of the drive pipe, the water from the test pump percolating through the disturbed drift materials alongside the drive pipe to the safe strata below, and in this manner polluting what was naturally an excellent water source.

Surface sources of water, excepting from uninhabited mountain districts where there is no domestic animal life which can impart a taint to the runoff from rainfall, cannot be regarded as safe for drinking purposes without purification by artificial means. Epidemics of typhoid fever have been traced in Switzerland and in this country, to water impounded from the rainfall and runoff on grazing lands, and this experience has led some profound investigators of the cause of typhoid fever to suspect that the colon bacillus from domestic animals when ingested with drinking water by the human system, may become the real typhoid bacillus as we find it in the urine or excreta of a patient, and in the human spleen of a cadaver. As great an authority as Prof. Ray Lankester has given some credence to this theory; while the late Dr. Edmund Rogers of Denver, Colorado, was inclined to believe from his own experience in the west, that typhoid fever can be contracted from a mountain water that had been polluted with the colon bacillus from domestic animals. So then the runoff from farm lands, aside from pollution from human sources, cannot be regarded as a safe water for drinking purposes, or for use in culinary operations. Health as well as sentiment prohibits it.

It is well known that the same kind of noxious excretions arise in farm houses as in city dwellings, and if these in any manner are disposed of so as to mix with and contaminate the runoff from the land around the farmhouses, they will pollute the water in some degree. Many farmhouses clustered together may be as much of a menace to the water running off from the lands, as will small vil-

lages which, as it is known, have furnished the germs for the origin of a typhoid fever epidemic in a community which has used such water for drinking purposes.

Impounded water in this state is seldom safe for domestic uses without filtration, or without the use of some germicide which is sure to destroy all possible pathogenic bacteria. Of all the sources of water supply possible in this state, water from deep tubular wells is the safest for sanitary uses. But nearly all the deep wells furnish hard water, which aside from organic infection, has objectionable properties which require consideration before it is acceptable for domestic purposes.

Water containing salts of lime and magnesia are difficult of use for laundry purposes, requiring that they should be "broke" or have the hardening salts precipitated before they can be conveniently used for this purpose. In the pioneer days the farmer made "lye" from hickory ashes on his own premises, and employed this to soften the "hard" well water when wash day came around. For steam purposes hard water is objectionable from the standpoint of coal economy, and sometimes is a source of real danger in boiler operations, by the deposition of lime and other salts on boiler tubes, thus impairing the circulation and perhaps sometimes leading up to boiler explosions. There is no corrosion from the deposited lime, but the safety, as well as economic effect of steam boilers, is dependent on a free and active circulation of the water around or in the tubes and flues, and the lining or covering of a boiler tube with a lime scale impairs the circulation.

Lime salts in drinking water contributes to "arterial sclerosis," or hardening of the arteries, by the deposition of calcareous matter in the blood vessels, rendering them brittle and liable to rupture under sudden increased blood pressure. This means that a man, if he values his life, as he grows older, if his drinking water comes from a limestone formation and is not artificially "softened" before he uses it, should be very careful not to get excited over the "tariff," the "European War," or the "McDermott" law, or it may result in partial paralysis, apoplexy, or the production of an "aneurism" by the rupture or stretching of a blood vessel rendered brittle or weak by the drinking of "hard water."

It will thus appear that a well water while absolutely safe from the infectious disease point of view, may contain other objectionable properties, which should be removed or counteracted before it will become in all respects safe for domestic and commercial uses.

Water softening apparatus is now so well exploited and so well understood that every public water works drawing from limestone sources should investigate the matter and adopt some approved method for removing the hardening salts from a well water supply before the water is sent through the mains to consumers. It should be borne in mind that water consumers who depend upon the public water supply are helpless in matters affecting water quality, and if you who own, operate, or conduct water works in the interest of a municipality do not look after these matters in the interest of your consumers, your consumers certainly cannot do it for themselves.

In early childhood, it is believed that a water containing marked quantities of lime, magnesia and sodium is good for the development of the bony system, for these and phosphates constitute the principal elements of the bones; but after the bones have reached their full development and no longer need nourishment, then an excess of lime and similar salts in the water may be a detriment to the human system, and a positive menace to life.

Iron similarly in excess in a water supply may enrich the blood too much in adult life and lead to boils and other kinds of blood poisoning, the blood then furnishing a favorable "nidus" for the germs of septic poisoning derived from the air, water, or from organic matter in decay. Sometimes a water rich in iron like "chalybeate water" may be necessary for people who are "anemic," but those in good health do not need it, and such water may work great harm to people who are otherwise in good health. Blood poisoning, as usually considered, is not a disease, but an accident, and the cause is not infrequently the use of water with iron in excess. The iron is in loose combination with other salts in water and is easily assimilated in the circulation, and largely increases the number of red corpuscles, and this may go to a point where the proper balance between the white and red corpuscles is disturbed, and the circulation is then easily susceptible to the germ of blood poisoning, which manifests itself in boils, carbuncles and in other ways.

The writer is not attempting to discuss a medical subject but to point out how a harmless metal, as usually considered, may be very harmful if found in excess in a drinking water. The iron content in a water, where found in conjunction with sulphate of lime, makes a thin hard scale on boiler tubes, and adheres to the iron tube like porcelain in a pan or kettle, is difficult to remove and reduces the efficiency of the heating surface of the boiler tube. Such a scale

cannot be cut out with ordinary tube cleaning "turbines" and often the only remedy when the scale reaches an objectionable thickness is to remove the tubes and insert new ones.

No one will willingly eat tainted food for fear of ptomaine poisoning, which, as we know, is often attended with fatal results. Why then should we drink a tainted water which is much more readily assimilated than solid food, and if under the law we are protected from foods unfit for human digestion, why should we not equally be protected from contaminated water supplies unfit for human ingestion? The state board of health in this and other states protects us as well as it can from dangerous public water supplies, but the chief work in this direction must be done by the men who are in control of the municipal and privately owned public water works of the state.

It is possible to drive a tube well through impervious strata to a reasonable depth alongside a reeking privy vault, and obtain a water wholly free from sewage contamination, but the risk is great and a safe thickness of impervious clay strata is so seldom found that the practice is not to be recommended, and safety lies in having such wells so far removed from sources of contamination that by no chance can surface pollution reach the water bearing strata penetrated by the well.

Ponds that are sometimes used as sources of water supply, while free from defined sewage pollution from animal or human sources, often contain algal growths which are productive of disease, although perhaps not of a fatal nature. Certain flora in stagnant ponds, or even in ponds with a slight current, impart odor and taste to the water and often are the cause of sickness due to the products of decay.

While this objection may not be serious from the health standpoint, nevertheless in some parts of the country and perhaps in this state, it has been the cause of considerable complaint and some real distress, and where such ponds are otherwise acceptable as sources of water supply, great care should be exercised to see that they are free from all algae by the application of copper sulphate, or some other chemical which will inhibit the growth of vegetation.

There may not be many ponds used as sources of water supply in Ohio, nor are there a great many that are capable of such use, and this objection is pointed out mainly to guard against an ill advised attempt to adopt some such sources in the absence of careful

investigation as to the character of the water and its probable influence on health. And where such ponds are liable to be used as sources of water supply, consideration must be given not only to the prohibition of floral life in and around the edges of the pond, but also to the probability of the water becoming at some time affected from the runoff from farmlands lying at higher elevation on the watershed, when the use of water from such a source will always require filtration, or some other effective method of purification.

If the filtration in such instances is accomplished by a so called mechanical, or rapid sand filter, with the addition of a chemical to form a coagulant to intercept the suspended matter on the beds of filter sand, or precipitate it in settling basins, this chemical with filtration or sufficient sedimentation, will also take care of any objection which may arise from the floral growth; although there may be a few instances, even in this state, where if the floral matter was not permitted to grow by the application of a proper chemical to the water such water might be used without filtration, or other mode of purification.

It will thus be seen from this brief statement that a selection of a source of water supply is not an easy matter, and particularly is it difficult where deep well sources are unavailable, or where the water thus obtained would be subject to other objections than those herein mentioned. For example, a water tainted with sulphur while safe from every other point of view, could not, and would not, be continuously used by any community, although a small amount of sulphur in the water might not be objectionable.

Water in falling on the earth and passing through the materials overlying the rock and through the fissures and pores in the stratified rock, dissolves and takes up more or less, of the mineral matter with which it comes in contact, and from this source is obtained lime, magnesia, sodium, iron and other salts which are found in water samples on analysis. Sometimes arsenic is found in water samples from mining operations, and this mineral, as we all know, is very dangerous to the human system.

In many instances, especially with small towns and cities where it seems extremely difficult to obtain satisfactory sources of public water supply, it would seem that this difficulty might be overcome, although perhaps at considerable expense, by selecting some sources from which a supply could be had large enough to meet the require-

ments of a number of such towns and cities, and provide that the pumping, and purification if required, shall all be done at one point, and the water then distributed to the various towns and villages requiring it.

Such source might in its natural condition be unfit for drinking water and other domestic uses, but when purified by some approved method, the water then would go to all the towns requiring it in a condition that would be safe to health, and if it happened to be a "hard" water it could be also softened at the point of collection and pumpage, when afterward it would also be entirely satisfactory for all commercial purposes.

PNEUMATIC PUMPING AS APPLIED TO MUNICIPAL PLANTS

By John Oliphant

TERMINOLOGY

To arrive at a thorough understanding of this subject and to facilitate the exchange of ideas, it is necessary to standardize the general terms used and determine what is meant by "percentage of submergence," "lift," etc. The following are the terms that have been generally accepted:

1. Static head. This is the normal water level when not pumping, measured from the surface on top of well casing.

2. Drop. Difference between the static head and the water level when pumping.

3. Pumping head. Level of water when pumping as compared to ground surface or top of well casing. Static head plus drop equals pumping head.

4. Elevation. Point above the ground surface or top of well casing to which water is raised.

5. Lift. Distance water is elevated from level when pumping to point of discharge. Static head plus drop equals lift when discharging at surface.

Elevation plus static head plus drop equals lift when discharging above the surface.

6. Submergence. Distance below the pumping head at which the air picks up the water.

7. 100 per cent. The vertical distance the air travels with the water from the point introduced to the point of discharge. Lift plus submergence equals 100 per cent.

8. Starting submergence. Distance below the static head at which the air picks up the water and includes drop plus submergence.

Bearing the above in mind and that 1 pound per square inch balances $\frac{2}{3}$ of a vertical foot of water and conversely 1 vertical foot of water exerts a pressure per square inch of 0.434 pound, it is easy to determine the starting pressure and operating pressure, remem-

bering, however, that the operating pressure consists of the water pressure above the submerged end of the air pipe plus the friction in the same.

SHUT-IN PRESSURE

By the following simple method, the pumping head may be determined while the air lift is in operation.

The *operating pressure* is made up, as before stated, of two factors: (1) The weight of the water standing over the jet when pumping. (2) The friction in the line conveying the air to the jet.

By eliminating the friction, we will have the weight of water above the jet, in other words.

PUMPING SUBMERGENCE

By placing a gauge in the air line between the well and a stopcock and quickly closing the latter, the gauge will register in pounds the water standing above the jet. This converted into feet will give the submergence. The depth of the jet being known, the water level when pumping can be determined. Care should be taken, however, that the gauge is correct and the reading should be taken as soon as the valve is closed, otherwise the inrush of water into the well may cause a rise in pressure, or a leak in the air line may cause a drop.

BACK BLOWING

This is a simple but efficient method of cleaning a well and increasing its flow and may be applied to sand, gravel or rock wells.

By closing the discharge of a well, the air pressure will force the water ahead of it back through the strainer and float the finer sand; then by opening the discharge after a short interval, the flow of the water to the surface will be resumed and the floating sand carried with it before it has time to settle. By repeating this operation, a large part of the finer material outside of and adjacent to a strainer may be drawn into the well and discharged at the surface and the coarser material collected around the outside of the screen will facilitate the inflow of water. This surging back and forth of the water and sand through the strainer will clean out the openings and dislodge accumulated sand that is found to clog up strainers where the water has flown for a long time in one direction.

In rock wells, the action of the drilling bit tends to force the cuttings back into the rock crevices, which the ordinary inflow lacks force to dislodge, but which the violent surge of back blowing will accomplish.

The alternate plugs of air and water are common to all forms of air lifts where care has not been exercised in properly mixing the air and water and properly proportioning the discharge piping.

TYPES OF AIR LIFT

There are three principal systems of air lift that are commonly used.

1. The Pohle system. This consists of an air pipe carried down outside of the eduction or discharge pipe into which it is either tapped through a street elbow at a short distance from the bottom, or turned up into the bottom.

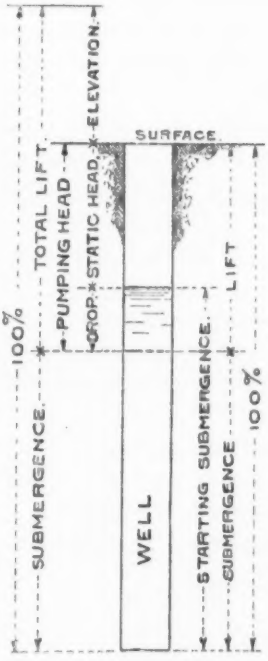
2. The central system. In which the air is carried down in a pipe suspended inside of the discharge, the water traveling up around the air pipe.

3. The reservoir system. This consists of an eduction pipe suspended in a casing allowing the air to pass down between the two and mix with the water at the bottom of the discharge pipe.

In all of these systems, the principle is much the same. The pressure is built up in the air passage to a point sufficient to overcome the head due to submergence and a large bubble of air passes into the discharge, forcing the water ahead of it and holding back that behind it. This flow of air from the air passage temporarily reduces the pressure so that the water held back overcomes the air pressure and rushes up, preventing the inrush of air until it builds up, breaks through and forms another bubble. This combat of air and water becomes rhythmic in its action and forms a succession of bubbles and water plugs in the discharge.

Theoretically, the expansion properties of the air as it travels towards the surface should form a perfect expansion pump, but, unfortunately, there are other natural laws that take effect and prevent this.

1. There is so little difference between the water and air pressure that the former flows into the latter at a low velocity and the bubble must travel some distance towards the surface before it expands sufficiently to fill the pipe and form the air plug, thus sacrificing a part of the submergence.



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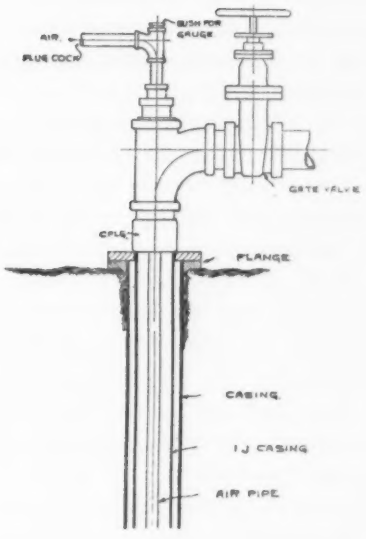

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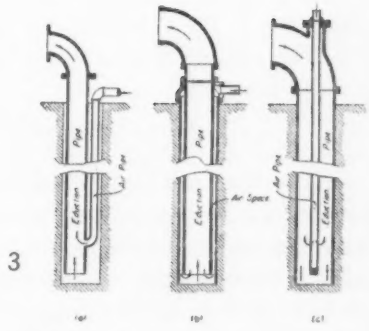

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FIG. 1. AIR LIFT TERMS

FIG. 2. ARRANGEMENT OF PIPING A WELL FOR BACK-BLOWING

FIG. 3. SKETCHES ILLUSTRATING FORMS OF "STRAIGHT AIR" LIFT

2. As the bubble of air travels towards the surface and the pressure above it decreases, it must expand, and as it is confined by the walls of the pipe, can only do this in a vertical direction, resulting in an increased velocity of flow and a greater displacement in the discharge pipe.

3. Owing to well known laws, the flow at the point of contact between a gas or liquid and the walls of passage is retarded, and, water being heavier than air, this effect upon the former is more pronounced until the water next to the walls of the pipe is pulled back around the bubble of air. The latter becomes elongated and at times slips through, joining the preceding bubble, this slippage representing a loss of efficiency and is manifested by the variation in the plugging discharge of this kind of lifts.

4. Air, like any confined gas, is always seeking a chance to escape, and any inequalities in the flow passage or abrupt changes of direction offer the opportunity it is seeking and a still further slippage results.

To counteract these defects, an air lift should be designed along the following lines:

1. A perfect mixture of the air and water into an emulsion at the point at which the air enters the water, so that the lifting effect of each minute bubble should commence at once and continue to the point of discharge.

2. An absolutely smooth passage for the air and water.

3. A properly expanded discharge pipe to take care of the air expansion as far as possible and prevent excessive friction.

4. The proper proportioning of the air and water pipes for the work to be done.

THE BOOSTER SYSTEM

The booster is a separating head or tank placed upon the top of the well to force the water to an elevation or through horizontal lines and utilize the same air that has lifted the water to the surface. The principle involved is as follows: The velocity of the air and water is always greater as it nears the point of discharge. This is demonstrated by the force of the discharge into the atmosphere. By discharging into a closed tank, the kinetic energy or sudden stopping of the column of water and air traveling under a high velocity recompresses the air and a certain amount of the power expended is returned. Compressed air under ordinary air

lift conditions is wasteful if used to force water horizontally, as the air being lighter than water goes to the top of the pipe and fails to bring the water with it. In the booster arrangement, the air does not follow the water but converts its volume into pressure before being allowed to escape, thus forcing a solid stream of water through the horizontal and vertical lines. It will readily be seen, therefore, that the discharge from any number of boosters may be connected into a common delivery pipe.

Another refinement of this system is to return the air from the booster to the inlet of the compressor.

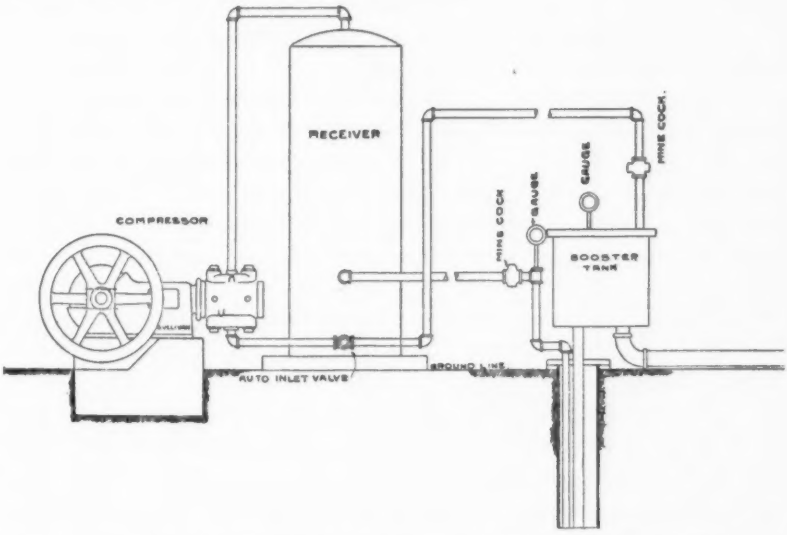

FIG. 4. LAYOUT FOR "BOOSTER" SYSTEM OF AIR LIFT BELTED AIR COMPRESSOR, AIR RECEIVER BOOSTER AND PIPING ARRANGEMENT TO WELL AND DISCHARGE

Utilizing the colder air: as every 5° the temperature of the air delivered to the compressor is reduced, a volumetric gain of 1 per cent is secured and a slight pressure; also reduces clearance losses in the air cylinder.

The following are some of the advantages of the air lift as compared to other methods of pumping from deep wells:

1. Quantity. It is an accepted fact that more water can be secured from a well by means of the air lift than by any other method, providing the conditions are proper for its use, on account of there

being no valves or obstructions in the discharge pipe, and a high velocity can be maintained.

2. Quality. While shallow wells may become polluted by surface contamination, properly constructed deep wells of municipal supply are found free from disease germs, as the casing driven down through hard pan above gravel formation or into rock shuts off surface contamination.

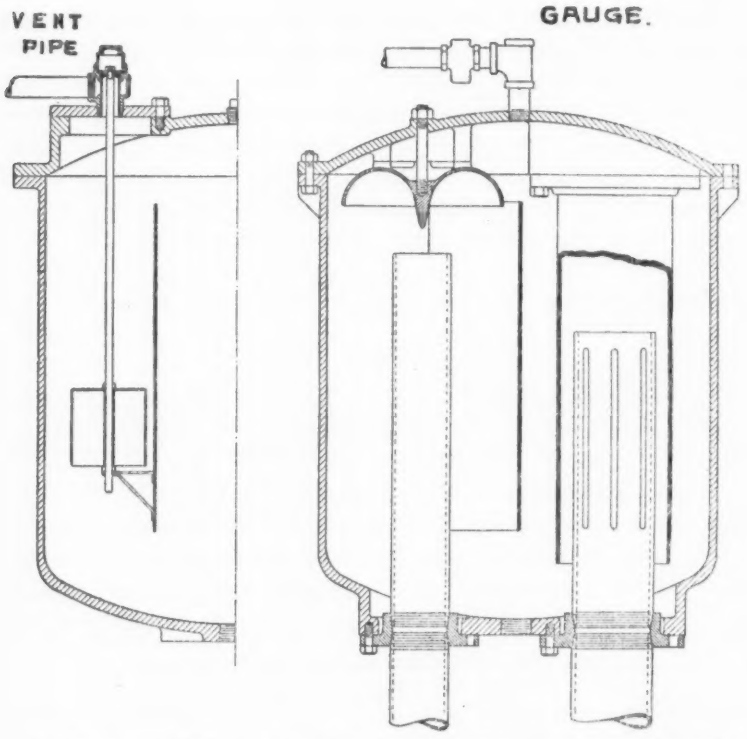

FIG. 5. SECTIONAL VIEW OF AN AIR LIFT BOOSTER, TO SHOW PRINCIPLE OF OPERATION

Gravel beds in or near a river can be made the source of a pure water supply by the drilling of wells and casing them low enough so that the water will be pulled down through the sand and gravel; the erosion of the river keeping the top of the infiltration bed clean.

Aeration is acknowledged to be one of the principal methods for purifying water.

Free sulphur gas is encountered in a large amount of underground waters. Ninety per cent of this gas is removed by the aeration of the air lift system, and the water from many sources of supply that is unfit for domestic use on account of this gas, when pumped by the direct acting pump is rendered entirely free from its odor and staining effects by the use of the air lift.

Most of the other solids contained in underground waters, while not thrown off, are rendered easier of treatment through aeration.

3. Temperature. As heat is driven from air by compression, through expansion it must reabsorb heat from whatever it comes in contact with. The expansion of the air in the eduction pipe will absorb heat from the water and lower its temperature.

4. Durability. The air lift installation is the most durable and requires less attention and repairs than any other pumping system. When once the well or wells are properly adjusted, the installation requires no further attention.

The water never comes in contact with any moving parts and the operating machinery is in the power house directly under the eye of the engineer, avoiding all pulling of sucker rods, making barrels, etc.

ENGINEERING

Although the question of pumping water from deep wells with compressed air seems to be a very simple one, and as a matter of fact, certain results are obtainable from a haphazard method of installation, yet a careful study of the conditions under which the wells are to be operated and the piping installed, as well as the compressor for the work, will repay very largely in the securing of more water at a less cost.

The question of well piping should receive careful consideration and the discharge pipe properly proportioned to the amount of water and air to be handled. For example: while one size discharge pipe may be of the proper size for lifting 100 gallons per minute at a lift of 50 feet and with 60 per cent submergence, yet to lift 100 gallons per minute with a lift of 100 feet and 50 per cent submergence, it will require more than double the amount of air than in the first instance and a larger discharge pipe should be used even for the same amount of water, to prevent high velocities and excessive friction. Then the lifting of a small amount of water through a large discharge pipe is wasteful. The pipe must be filled

with water or air so that a small amount of the former requires a large amount of the latter, or it will bubble through and not bring the water with it; and to supply enough air to blow the water up is a wasteful operation.

The conditions often change in wells that have been in operation for a long time. The general dropping of the water plane will change the proportion of lift and submergence. Tests should be run and a readjusting of the piping made.

Very often screens and gravel strata may be clogged up, and back blowing as heretofore described will often bring the wells back to their original capacity.

The whole question of the well installation should receive just as careful engineering attention as the pumps, boilers, or any other parts of the plant, and this attention will be productive of a greater increase in efficiency, because it is more often overlooked or neglected; the general idea being that the air lift is bound to be inefficient and let it go at that, whereas, with slight expense, a large saving in operation can in the majority of cases be obtained.

EARTHING ELECTRICAL SYSTEMS TO WATER PIPES[1]

By Burton McCollum and O. S. Peters

The protection of persons and property against electrical dangers has in recent years become an important problem. In the beginning of the art of distributing electrical energy to consumers voltages were low, direct current was used, and in the case of each system the points of consumption were confined to a comparatively restricted territory. Then the dangers to persons from electrical circuits were practically negligible, but the dangers to property were not, because insulation and methods of construction were undeveloped. At the present time, however, far different conditions exist. Electrical systems have been enormously extended, and the demand for economical operation of the extended systems has brought about the use of voltages greatly exceeding those used in the beginning. The development of alternating current machinery and methods of transmitting electrical energy over long distances has been chiefly instrumental in bringing about the new conditions. With the increase in the voltages at which electrical systems are operated, dangers to persons and property have multiplied. It is true that improvements in methods of construction and quality of insulation have kept pace with the growth of electrical systems, or vice versa, whichever way one chooses to look at it, but at the same time many dangers arise from electrical circuits which require special means and devices to render them harmless. One of the most important sources of danger is that due to the close proximity between highvoltage and lowvoltage circuits in transformer windings, on pole lines, in manholes, and other places where, for lack of space or for other reasons, it is necessary to place such circuits near each other. The actual danger in this case arises from the entrance of voltage and current from the highvoltage circuit upon the lowvoltage circuit through faults in insulation, contacts between wires and in other ways. The great importance of this source of danger is due to the fact that large numbers of people are continually

[1] Read at Central States Section Meeting.

coming in contact with apparatus and appliances connected to these lowvoltage circuits. It is, therefore, the duty of persons installing such circuits to make them as safe as it is practicable to make them; and it is, moreover, to the best interests of everybody concerned with them that they should be made safe. Much can be accomplished in this respect by connecting these lowvoltage circuits to earth in the proper manner. It is the purpose of this paper to discuss briefly the principal causes of the dangers just mentioned, the desirability of connecting lowvoltage secondary circuits to water pipes to avert these dangers, and also the effect on the pipe systems of such earthing.

DANGERS FROM ELECTRICAL SYSTEMS

The most common forms of lowvoltage circuits are those fed from highvoltage alternating current circuits through stepdown transformers. In this case the danger arises from the entrance of current and voltage from the highvoltage circuit either through leaks in transformer insulation or contacts between wires. Leaks in transformer insulation are caused in most cases by lightning striking the line and puncturing the insulation between windings. Much effort has been expended in developing lightning arresters to take care of these lightning strokes without injury to the transformers, and much has been accomplished, but complete protection is not now obtainable. Contacts between line wires result from storms, electrical accidents to cables and other causes.

As an example, take a transformer connected to a 2200 volt distributing system which transforms energy for lighting a group of dwelling houses by means of a 3-wire 110 to 220 volt circuit. If during a storm a highvoltage line wire breaks and falls on a lowvoltage wire, or any one of the possible accidents occurs which may have a similar result, a condition may arise such as that illustrated in figure 1. That is, one side of the lowvoltage circuit is, in effect, connected by a wire to one side of the highvoltage circuit. If both circuits are insulated from ground at all points, an electrostatic voltmeter, or some other voltmeter which takes but slight current to operate it, will show at V a difference of potential approaching 1100 volts between lowvoltage circuit and ground, the actual voltage indicated varying with a number of factors. It is not likely, however, that either circuit will be thoroughly insulated at all points. There may be faults in the insulation, and if there are the

voltmeter may read as high as 2200 volts. This would be the case if the opposite wire of the highvoltage line were down and touching ground somewhere, or were even in contact with a tree.

In either case if the lowvoltage circuit were in any way accidentally grounded, the flow of current to ground might be considerable. In the first case the current flow that might occur would be due to

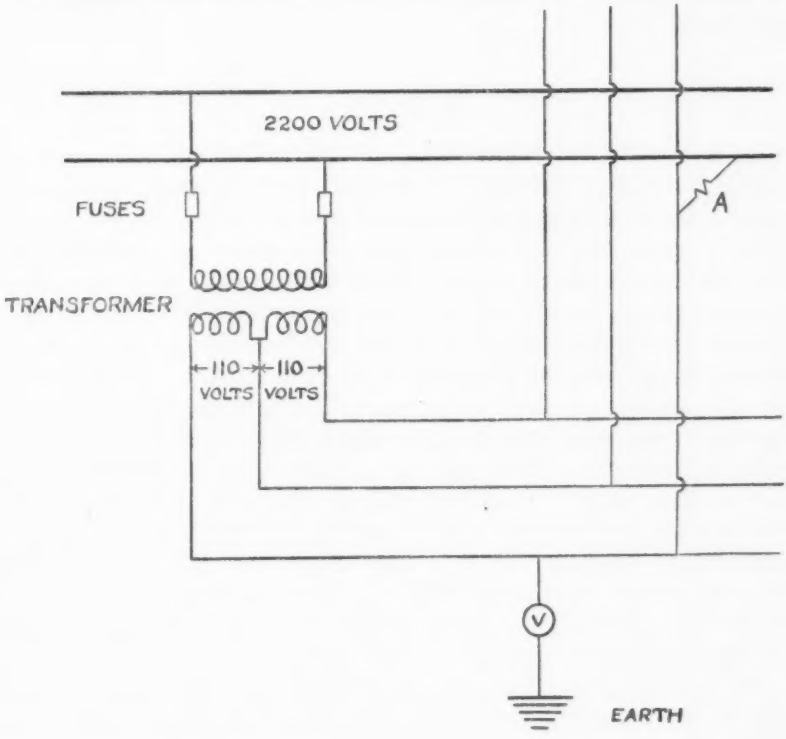

FIG. 1

the electrostatic capacity between the highvoltage line and ground, the line acting as one plate of a condenser and the earth as the other. The alternating voltage of the line itself would tend to charge and discharge this condenser through the fault *A* in figure 1 in series with whatever accidental ground happened to be on the lowvoltage circuit. This might be the body of a person in contact with lighting fixtures. The value of this condenser current can be shown

to be about 10 milliamperes per mile of line. The magnitude depends directly upon the length of the line so it would reach a dangerous value with a length of line of 10 miles. In the second case the current would depend upon the sum of the resistances between lowvoltage circuit and ground and between the opposite wire of the highvoltage circuit and ground. Similar conditions may arise with any lowvoltage circuit if it comes in contact with a highvoltage circuit.

PROTECTION AGAINST THE MAXIMUM DEGREE OF DANGER

It is obvious that when there do exist such high voltages between lowvoltage circuits and ground there is great danger to persons handling lamp sockets and other appliances; moreover, there is an extreme likelihood of fire following a failure of insulation of the lowvoltage circuit because of current flowing from the highvoltage circuit to ground and heating inflammable substances. The frequency with which fires and accidents are reported from this cause is sufficient evidence of its seriousness. The condition described above, however, represents the maximum degree of danger which can arise, and the one which is likely to be met with the most infrequently. There may be a lesser degree of danger; such, for instance, as that which would be brought about by a failure of transformer insulation at some place beyond the end turn of the highvoltage winding. In that case the voltage to ground might be only a small fraction of 2200 volts and the danger proportionately less. But it is necessary to protect against the full voltage because this will frequently be encountered.

It is evident, therefore, that in the case of lowvoltage circuits fed through transformers from highvoltage circuits, or where a lowvoltage circuit of any kind is liable to contact with highvoltage circuits, great precautions are necessary to prevent accidents; furthermore, the best available means and devices must be used. From the dangers just described a great deal of protection can be obtained by connecting the lowvoltage circuit to earth as in figure 2. For the best degree of protection it is necessary that the resistance to flow of current from the lowvoltage circuit through the earth wire B and earth connection E be very low. That is, a current must easily pass from the lowvoltage circuit into the earth in case of contact with a highvoltage line. If this is the case, and

the resistance to flow of current is low enough, a dangerous voltage can not exist between lowvoltage circuit and ground. For example, instead of the voltmeter at V in figure 2 reading between 1100 and 2200 volts, as it did under the condition shown in figure 1, it will now read a value which may be found by multiplying the current flow in amperes in wire B by the resistance in ohms to flow

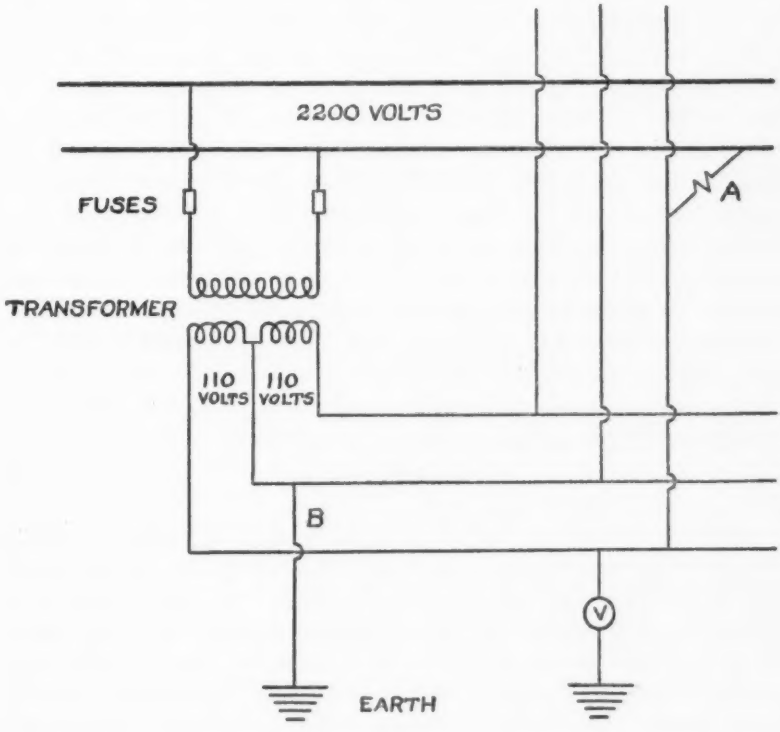

FIG. 2

of current into the earth at E. If the resistance at E is low, the voltage measured at V will be low even though a large current is flowing. The lower this voltage is the better, and for a high degree of safety it should in no case exceed 150 volts. The current which will flow in wire B depends upon the current carrying capacity of the protective devices on the line from which the current comes. This may be small or large, and the maximum allow-

able resistance in the earth connection at E will depend upon the maximum value of this current. The maximum current which a line will carry permanently is limited by the rated current of the fuses or automatic circuit breakers which protect it from overload. Hence, the maximum allowable resistance in the earth connection can be expressed by the following formula: $R = \frac{150}{I_A}$, where R is the resistance in the earth connection, 150 is the allowable voltage between lowvoltage circuit and ground, and I_A is the current required to operate the fuses or circuit breakers which open the circuit. If this current is 100 amperes, R will be 1.5 ohm; 200 amperes, 0.75 ohm, and so on. One hundred-fifty volts, however, is the maximum allowable voltage rise between lowvoltage circuit and ground. There is a slight possibility of danger from this voltage even, but only under special conditions; so, for practical purposes 150 volts may be considered as a safe limit. Serious accidents to persons from potential differences between lowvoltage circuits and ground of 150 volts or less have been reported only as having happened in very damp locations, or in other places where extraordinarily good contact was made with both lowvoltage circuit and ground.

EARTH CONNECTIONS

The next question is that of obtaining a low value of resistance for the earth connection E. There are several methods by means of which electric circuits can be earthed; namely, by utilizing water pipe systems, driven pipes or buried plates. Buried strips of metal of any desired length may also be used under special conditions, and there are on the market many patented devices for making earth connections. In this list, however, waterpipe systems easily come first in point of desirability. In the first place, on account of their great extent, they offer but little resistance to flow of current away from them into the earth, the resistance of water pipe earth connections being found to be but a fraction of an ohm in most cases. A resistance of 2 ohms would be extraordinarily high. As pointed out later, however, where these low resistances are found the pipe joints for a considerable distance from the earth connection must give as good metallic contact as will ordinarily be found with lead or screw joints. In the second place, water pipes are easily accessible at service pipes or at other places; and, in the third place, it

can be shown that with certain precautions all possibility of damage to the pipes, or injury to employees of the water company can be easily avoided. In fact, many dangers considered of importance in the past do not exist where the grounding is properly done.

With regard to driven pipes, buried plates, or strips of metal, and patented earthing devices, table 1 gives the results of measurements

TABLE 1

Resistance of earth connections. Kind of earth, clay rather stony. Earth connections in place four months and soil fairly moist when measurements were taken.

Type of Earth Connection	*Resistance ohms*
Strips of galvanized iron 1½ inches wide, 20 feet long, in clay 12 inches deep (average of 8)	30
Strip 160 feet long in clay 12 inches deep	5
Strip 60 feet long in trench 12 inches deep with 4 inches of coke in trench, covered with clay	8
Strip 60 feet long in clay 12 inches deep with 1 pound of salt per foot of strip	6
Paragon ground cones 2 feet long, 5 feet deep, in coke (average of 2)	57
Paragon ground cones 1 foot long, 5 feet deep in coke (average of 2)	72
Maxum ground boxes 5 feet deep in clay (average of 3)	52
Brach hydroground, large size, 5 feet deep in clay	61
Brach hydrogrounds, medium size, 5 feet deep in clay (average of 3)	64
Lord disc type hydrogrounds, 5 feet deep in clay (average of 2)	83
Federal Sign System 22 inch cartridge ground plate, 5 feet deep (average of 2)	30
Federal Sign System 10 inch cartridge ground plates, 5 feet deep (average of 2)	59
Plates, 2 by 4 feet, on edge in clay 5 feet deep (average of 3)	33
Plates, 2 by 4 feet, flat in clay 5 feet deep (average of 2)	43
Plate, 2 by 8 feet, flat in clay 4 feet deep	32
Plate, 2 by 8 feet, in coke, 4 feet deep	17
Plate, 2 by 8 feet, in salted earth, 4 feet deep	8
Pipe earths, ¾ inch pipe, 5 feet deep (average of 8)	73
Pipe earths, ¾ inch pipe, 10 feet deep (average of 8)	52

on a number of these forms of earth connections made in rather stony clay at the Bureau of Standards. These measurements represent a part of the results of a thorough study of the subject of earth connections for electrical systems which is now being made by the Bureau. The table is practically self explanatory, and shows in general that a low resistance, or a resistance low enough effectively

to avert danger of the kind just described, is not easy to obtain by means of any of these devices. In considering the results given in table 1 it should be borne in mind that the resistivity of the soil in which these earth connections were made is considerably higher than the average of that found in practice; although the soil in some places will be of even higher resistance and hence worse for the purpose of making earth connections than that described. It may also be stated as a well known fact that if pipes are driven into the earth at a distance from each other and connected by a wire the combined resistance to flow of current away from the several pipes into the earth will be much less than that of a single pipe. In fact, for pipes driven at 10 feet or more from each other the resistance to flow of current away from them into the earth is roughly inversely as the number. That is, with two pipes driven from 6 to 10 feet from each other the resistance is a little more than half that for a single pipe, with three pipes the resistance is a little more than one-third that for one pipe, with ten pipes one-tenth, and so on. As just stated, this is only roughly approximate and as the number of driven pipes increases the distance between them must also increase in order to maintain even the approximate relationship between number and resistance.

If the resistance of a single driven pipe earth connection in a certain locality were as low as 15 ohms, to obtain a resistance comparable with that of a waterpipe system in the same place would therefore require 50 or 60 pipes driven into the earth at 10 to 20 feet distant from each other and electrically connected together. This is plainly impracticable. It must be granted, of course, that by the use of driven pipes or buried plates a certain degree of protection can be obtained; in the case of small transformers and lines of limited capacity even an ample degree of protection; but as the kilowatt capacity of the lines and transformers increases the resistance required of the earth connection must decrease. The practicable limit of decrease of resistance with driven pipes or buried plates is soon reached, and for the circuits of larger capacity it is imperative that some other means be found. In fact, for all lowvoltage circuits it is highly desirable to have low resistances in the earth connections. The most obvious solution of the problem is to use water pipe systems which, in most cities, cover approximately the same areas covered by the electrical systems. To connect to the water pipe systems is highly advantageous to both the electric company and the consumer.

There are, of course, localities not reached by water systems and in such places it is necessary to resort to driven pipes and other means of making connection to earth. As stated above, where the installations are of small power rating an ample degree of protection can be obtained with driven pipes, and considerable protection even in the case of fairly large installations. In no case should earthing be omitted. If there is sufficient ground space available a number of pipes can be driven to a depth of 8 or 10 feet at a distance of 5 to 10 feet from each other and connected together. If space is lacking, 3 or 4 pipes driven to a depth of 10 feet around a pole will give a resistance which in many cases may be considered sufficiently low. Three pipes driven around a pole and close to it, will be found to have a resistance of approximately 50 per cent of that of one of the pipes.

EFFECT ON WATER PIPES OF USING THEM AS EARTH CONNECTIONS

It has been shown above that it is very desirable to connect lowvoltage secondaries to water pipes. It must also be shown, however, that the use of the water pipes for making earth connections is not in any appreciable degree a disadvantage to the pipe owning company. In the past it has been stated that trouble for the company would arise from three sources: (1) Electrolysis by stray currents from the earthed circuits; (2) danger to employees of the water company while working on service or other pipes to which lowvoltage circuits were earthed; and (3) complications from allowing a second public service company the use of the pipes.

The subject of electrolysis in this case may be considered under two heads: (a) electrolysis by alternating current, and (b) electrolysis by direct current.

a. Electrolysis by alternating current. Referring to figure 3, *A* represents an extensive lowvoltage alternating current circuit which is earthed at a number of points to service pipes, these service pipes being all connected to the same water system. It is readily apparent that under normal conditions of operation, or with insulation everywhere in good condition, the opportunity for current flow in the pipes is very slight. With unbalanced load on the system current would flow in the middle wire, setting up differences of potential between the points *e*, *f* and *g*. This would cause current to flow in the pipes, but the voltages between *e*, *f* and *g* being

necessarily small, the currents would be small, since there is more or less resistance in the pipes. In no case would the current flow exceed a fraction of the flow in the middle wire.

On the other hand, there can be no interchange of current between circuits *A* and *B*. In order for this to occur, the flow would have to take place from *A* through earth wires *a*, *b* and *c* in parallel, over the water pipe to wire *d* and circuit *B* and back to *A* on the

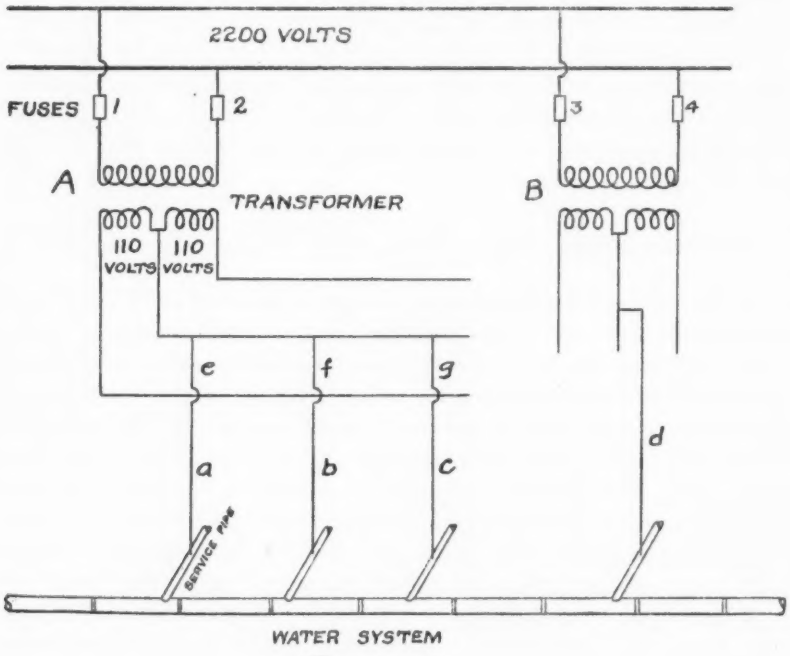

FIG. 3

highvoltage line. Two layers of transformer insulation prevent this, so such an interchange of currents is impossible, unless there are faults in the insulation of both transformers. If this should occur fuses 1, 2, 3, or 4, would be likely to go out and isolate the lowvoltage circuit. Or, if the fuses did not go out, the current would be limited to their rated capacity. With a lowvoltage circuit connected to the pipes at a single point or as in *B*, figure 3, there is obviously no opportunity for any but the very slightest flow of current into the pipes over wire *d*, because there is no place for

it to go. The slight current that would flow would be due to electrostatic capacity effects and would hardly be measurable by any ordinary means.

With a condition existing such as that shown in figure 1, however, considerable current might flow for a greater or less time. If the leak should occur to circuit *A*, for example, the current would pass from one side of the highvoltage line through the fault to circuit *A* and to the pipes over earth wires *a*, *b* and *c*, whence it would flow through the earth back to the opposite side of the highvoltage line.

Nevertheless, granted that under normal conditions of operation slight alternating currents may flow, and that in the event of failure of insulation large currents may flow, it has been shown by experiments recently conducted at the Bureau of Standards that the damage by electrolysis from such currents is practically negligible. These experiments, made on both iron and lead, in moist clay, show that with alternating current at commercial frequencies the amount of metal dissolved is but a fraction of 1 per cent of that dissolved by direct current, the quantities of electricity passed being the same. To express the same thing in different words, it may be said that with currents in pipes which are equal in point of quantity of electricity passed, it will take the alternating current hundreds of years to accomplish the damage that would be accomplished by the direct current in a single year. Therefore, from the stray alternating currents which may be found in pipes from earthing lowvoltage alternating current circuits to them no perceptible damage through electrolysis need be feared. The only possibility of damage is that due to heating if the current flow is heavy, but the likelihood of such currents flowing is so small as to be of no importance. Unless the pipes were very small the currents required to damage them would be thousands of amperes, values beyond the range of possibility in any ordinary case.

It has been stated by some that the passage of electric currents over service pipes may heat the water in them which will result in swelling and sticking in the hard rubber parts of water meters. Such cases have, in fact, been reported, that is, where hot water has been the cause of damage to meters. That such heating can be due to electric currents in the pipes, however, is not likely. It is more likely to be due to the backing up of hot water from water boilers into the service pipes caused by overheating and forming steam at pressure sufficient to force the water out of the boiler. Such

cases have been investigated and found to be the result of hot water from water heaters. One case, however, has come to the notice of the Bureau in which a street railway track was bonded to a service pipe and in this case the current flow was the cause of considerable heating. With the ordinary lowvoltage alternating current circuit, on the other hand, the possibility of sufficient current flow to cause heating is very remote.

b. Electrolysis by direct current. Electrolysis by direct current may arise, or be increased in two ways. In the first place, where the middle wire of a lowvoltage direct current system is earthed to a pipe system at a number of points, the pipe forms a conductor in parallel with the middle wire, in which case when current flows in the middle wire current will also flow in the pipes. If the resistance of the pipes is comparable in magnitude with that of the middle wire these currents will also be comparable, being shared in inverse proportion to the resistances. This is the same condition as was shown in the previous paragraphs to exist in the case of lowvoltage alternating current circuits, but with the alternating currents the damage is negligible, whereas in the case of the direct currents the damage may be serious, because of the marked corrosive effects of direct current. Earthing direct current systems to water pipes at a number of points is therefore undesirable, and such earthing should be confined to but one point on the system, and that at the power house.

Earthing the middle wire at more than one point is unnecessary, and even when earth connections are made, say, with one to the water system at the power house and others to driven pipes or plates, current flow may be considerable and lead to undesirable results. It is to be recommended, therefore, that the middle wire of 3-wire direct current systems be earthed at the power house only, and all other earth connections to the middle wire omitted. An exception to this can be made in the case of connections to service boxes, because in such cases the resistance to ground will in general be high. There can, however, be no serious objection to earthing to pipe machine frames, conduit, or other metallic objects near or enclosing direct current circuits, and it is desirable to earth them to promote personal safety and safety to property. In this case current would flow only while faults existed in the insulation, and since this flow would be temporary, lasting only until warning could be given of the fault and repairs be made, the resulting damage would be negligible.

In the second place, electrolysis may be increased or transferred from one locality to another, if a lowvoltage circuit of any kind is earthed at different points to two metallically separate pipe systems. For instance, in cities where electric railways with ground return are in operation it may be found that one pipe system is at a considerable difference of potential with respect to another. If a lowvoltage circuit is earthed to both of them current will flow from one pipe system to the other, with danger of overheating the wires

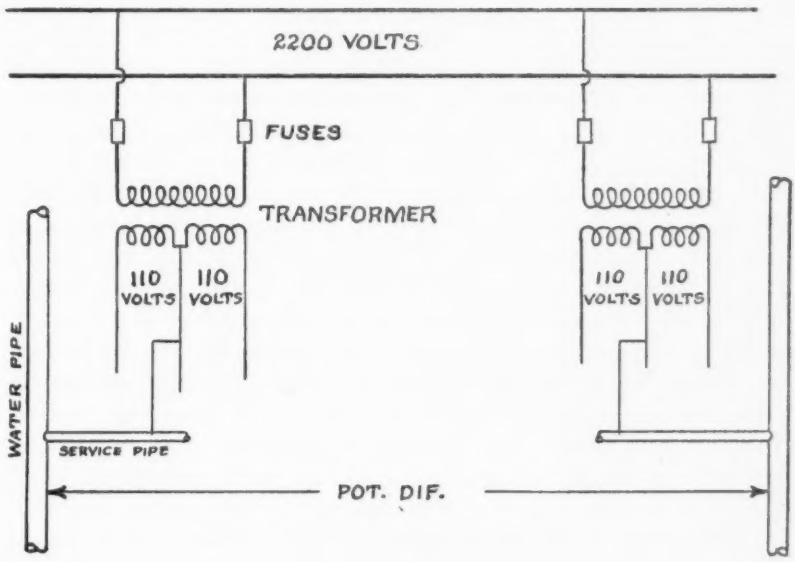

FIG. 4

and also of increasing electrolysis on the other system. Moreover, if a lowvoltage circuit is earthed at one point to a pipe system that is at a potential difference of several volts against earth, and at another point to the steel work of a building the steel work of the latter takes the potential against ground of the pipe, and danger of electrolysis in the building ensues. On the other hand, if different lowvoltage circuits fed from the same highvoltage distribution circuit are earthed to different pipe systems no current can flow from one pipe system to the other, because, as shown in figure 4, the insulation between transformer windings prevents the flow of current,

and current flow would necessarily have to take place over the high-voltage line in order to get from one pipe system to the other. This might occur, of course, if there were faults in the insulation of both transformers, but this is a contingency that can be neglected.

Hence, this general rule can be laid down. In every case where it is necessary and allowable to earth a lowvoltage circuit at more than one point, the earthing should be done to the same pipe system, and in no case should separate pipe systems be used.

INSULATING JOINTS

In connecting a lowvoltage circuit to a pipe system at more than one point, it is important that there be no insulating joints in the pipes that may come between the points of connection. If insulating joints are present, the lowvoltage circuit will act as a shunt to the joint and heavy current flow over the wires may follow if stray currents from street railways are on the pipes. This presents a dangerous condition because of the possibility of fire, and in the case of direct current systems, of increased electrolysis, and should be avoided. Moreover, if there are insulating joints near a point where an earth connection is made to a service pipe, the joints may so restrict the useful pipe surface in contact with the soil as to cause the resistance to current flow from the lowvoltage circuit into the earth in case of an accident to insulation to be so great as seriously to impair the usefulness of the earth connection. For this to be the case it is, of course, necessary to have insulating joints on both sides of the point where the earth connection is made. With an insulating joint on one side of an earth connection and lead or screw joints on the other for several hundred feet the earth connection may be considered good. With insulating joints nearby on both sides, however, as would be the case with a cement joint pipe line, the earth connection would not be very effective. Therefore, in making earth connections using water pipes it is very important to know the character of the joints in the pipe.

PICKING UP STRAY CURRENTS BY LOWVOLTAGE CIRCUITS

If a lowvoltage circuit is earthed to a lead jointed pipe system at several points, and there is current flow in the pipes from electric railway circuits, the current picked up by the lowvoltage circuit is not likely to be of importance. This is due, first, to the fact that

lowvoltage circuits are in most cases of limited extent, and hence do not include enough of the pipe line to be subject to a large voltage drop, and, second, to the fact that the resistance per unit length of the middle wire is in most cases large compared with the pipe line This refers more particularly to alternating current circuits.

DANGER TO EMPLOYEES OF THE WATER SYSTEM

The question of danger to employees of the water company has been many times discussed. In general, it may be stated that danger is likely to arise in only one case and that is illustrated in figure 5.

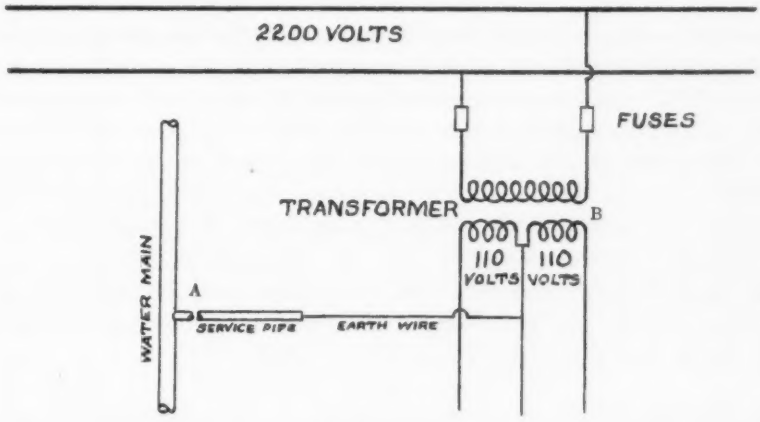

FIG. 5

This shows a lowvoltage circuit earthed at one point to a service pipe, a failure of transformer insulation having occurred at *B*. If the service pipe is disconnected at *A* the person making the disconnection is liable to an electric shock. The severity of the shock depends upon a number of factors which have previously been discussed, and it has been shown that conditions may easily arise under which the severity of the shock would be great enough to cause death. Therefore, with lowvoltage circuits earthed to service pipes at a single point precautions are necessary to prevent such accidents to employees of the water company when working on them. This can be readily provided for by requiring the electric company to disconnect earth wires from service pipes when work is to be done on the pipes and reconnect when the work is finished. This is a

reasonable sufficient requirement, and has been in force in several places for years with satisfaction to both parties.

With multiple earth connections to water pipes, however, as shown in figure 3, even the precaution mentioned above is hardly necessary. Unless all of the service pipes to which earth wires have been attached are disconnected there is very little danger. A person may work on one of the service pipes in perfect safety as far as electric shock is concerned if the other service pipes are undisturbed. Moreover, it is an advantage to the consumers using the circuit to have more than one connection to the water pipe, for if one of the wires become disconnected the others still maintain the circuit in a condition of safety. Multiple connection of lowvoltage alternating current circuits to water pipes is therefore to be recommended and encouraged. It should be emphasized again at this point, however, that these multiple connections should be confined to a single water system, for reasons previously set forth in this paper. Moreover, when multiple earth connections to water pipes are made, the resistance of the pipe line between the two farthest removed points of connection should be measured in order to make certain that no insulating joints are present. If there are no insulating joints the resistance will in general be found to be but a small fraction of an ohm. If there are insulating joints it may be as much as an ohm or even several ohms.

MECHANICAL CONSTRUCTION OF WATER PIPE EARTH CONNECTIONS

Where connection is made to a castiron pipe line with bell and spigot joints the most satisfactory method is probably that prescribed by the National Fire Protection Association. This connection is made by drilling a hole in the bell, tapping it, and screwing in a brass plug to which the earth wire is soldered. This joint can be made with a reasonable amount of labor and will be permanent, especially if the surface of the plug and pipe in the immediate vicinity is heavily coated with pitch or something else to prevent corrosion. Where connection is made to service pipes which can be drained of water while work is being done on them the earth wire can be wrapped several times around the pipe and soldered to it. If the service pipe cannot be drained conveniently the next best thing is a clamp to go around the pipe, with a lug to which the earth wire can be soldered. There are a number of amalgams

on the market with which the pipe can be treated before putting on the clamp, making a better electrical connection between pipe and clamp than would otherwise be attainable. Many of the clamps sold for this purpose, however, seem of rather flimsy construction. To obtain good results a clamp of sturdy construction is necessary; otherwise it is difficult to get as good a contact with the pipe as is in most cases desirable.

The point at which connections to service pipes are made must be considered. This will in most cases be determined by local conditions. In general, however, it may be stated that this point must be chosen so that there is the least likelihood of the pipe being disconnected between the earth connection and the water main. It is desirable that the earth connection in all cases be placed beyond the point where the service pipe is likely to be disconnected by plumbers altering or repairing piping in buildings. Where the water meter is placed in the basement of a building the earth connection should be made on the street side of the meter if possible. If it is not possible, or if the meter is located in a well or manhole under the sidewalk or street, a jumper, consisting of a wire as large or larger than the ground wire should be placed around the meter, connection being made to the pipe in the same way as for the ground wire.

CONNECTING TO GAS PIPES

Connection directly to gas pipes should in every case be prohibited. The reasons for this are as follows: In the first place many gas mains are laid with insulating joints which are extremely undesirable in a pipe line to which earth connections are to be made. In the second, if a gas pipe in which even a small current is flowing is disconnected a spark may follow and cause an explosion or a fire. In the third place where there are gas pipes there are in nearly all cases water pipes, so connection to the gas pipes is unnecessary.

On the other hand, the connection of lowvoltage alternating current secondaries to water pipes should not only be permitted, but be made compulsory. Such connection has been shown to obviate a hazard that might otherwise arise when lightning or other cause breaks down the insulation of transformer, or wires become crossed. Inasmuch as a considerable advantage to the public results from such earthing, with no appreciable disadvantage to either public service company, there is no good reason why city ordinances or other legis-

lation to require it should be longer delayed. In numerous localities the practice has been tried and found desirable and it should be extended to all localities where highvoltage alternating current distribution systems are in use.

SUMMARY

1. Many of the dangers which arise from electrical circuits may be eliminated by earthing these circuits.

2. Of the means of earthing electrical circuits water pipes are by far the most desirable.

3. There is no danger of electrolysis by such stray alternating currents as may result from earthing lowvoltage alternating current circuits.

4. Direct current circuits should be earthed at but one point, preferably at the station.

5. Where conditions permit two or more ground connections should be made on each secondary system.

6. In the case of any individual lowvoltage circuit in which a number of earth connections to pipes are made the earthing should be confined to one pipe system. Measurements of the resistance of the pipe line between the farthest removed points of connection should be made to make certain there are no insulating joints in that part of the pipe line which may cause the electric circuit to carry heavy stray currents from railways.

7. In making either single or multiple earth connections to water systems, unless it is positively known that there are no insulating joints nearby, the adequacy of the earth connection should be determined by measurement of its resistance. Earth connections should not be made to cement joint lines, or other lines in which there are many joints of high resistance.

8. Connection to pipe lines may be made by screwing a brass plug into the bell in the case of castiron pipes, or by clamps or soldering to service pipes. Soldering is preferable to clamps where it is possible to do it.

9. Earth connections to service pipes should be made at the point where there is the least likelihood of the pipe being disconnected between the connection and the main. If the water meter comes between connection and main a jumper of the same size as the ground wire should be put around it.

10. Earth connections to gas pipes should be prohibited chiefly on account of the chance of explosions or fires, and also because the almost invariable presence of water pipes makes such connections unnecessary.

11. Because of the great advantage to the public and the slight disadvantage, if any, to the public service corporations resulting from earthing to water pipes such earthing of secondary systems should be made compulsory.

DISCUSSION

MR. H. C. HILL: If the companies grounding their telephones use the service pipe in the house, will it affect the telephones in any way?

MR. BURTON MCCOLLOM: There probably would be a little disturbance of the telephone system during the time when the high voltage is crossed with the low voltage wires. There then probably would be enough voltage between this ground point and the earth to give a little disturbance, but that is an unusual condition, and it would never be allowed to exist for any length of time, and would be extremely rare.

MR. H. C. HILL: There is a very general practice with telephone companies in some localities to simply solder on to the house service pipes in making their ground.

MR. BURTON MCCOLLOM: It is all right to do that. They get a ground for lightning protection, and it is not only a protection to the telephone company but is in reality put in primarily for the protection of the user of the telephone, and because of the fact that it is a measure of public safety, it is something that ought to be encouraged rather than discouraged. The same thing applies to grounding secondaries and transformers to water pipes. That is of no aid to the water company, except that it is a measure of public safety, and consequently something that the water company should encourage.

MR. H. C. HILL: The question was whether that would have any effect on the telephones.

MR. BURTON MCCOLLOM: Not if it is properly done.

MR. O. H. HUTCHINS: The speaker is not a water man, but an electric light man, but would like to ask a question. Mr. McCollom seemed to be pretty positive in his statement regarding the grounding of neutral to direct current systems, one ground in his estimation being sufficient. Now, not being disposed at all to disagree with Mr. McCollom, but, on the contrary, to agree with him, the question that arose in the speaker's mind was, if that is satisfactory, why is it not just as satisfactory to establish one good ground at the transformer of three wire secondaries, rather than to depend upon a multiplicity of grounds through the various customers' premises? It would seem that the same argument would apply there, that, if it would be satisfactory to a direct current, it would be satisfactory for alternating current.

MR. BURTON MCCOLLOM: If you can be sure of getting a good and permanent ground at one point, that is usually sufficient. You need but one permanent ground. The difficulty with having only one ground on each transformer secondary is two-fold. First, there are so many of them in any large distribution system that you cannot give them the maintenance attention that you can give one ground on the D. C. system at the power house. In the second place, the neutral wire of your transformer service generally extends a considerable distance from the transformer serving a number of customers, as a rule, and further, it is a rather small wire, very small compared with the size of conductors we would always have on the D. C. system, and the danger of breakage in the small neutral wire at some point is very much greater than the danger of breaking of the cables usually found in the Edison system, so that there is a much greater probability of the failure of the single ground on the transformer than of a failure of the ground at the power house. That is the principal reason why the speaker would recommend multiple grounds in the case of the transformer secondary, and not recommend it for the D. C. system. It might be added that where the transformer secondary is one of very large power supply, where you have to have large cables, that are not likely to be easily broken there is much less reason for supplying multiple grounds, providing you are sure that the ground you do make is a good and permanent one.

MR. O. H. HUTCHINS: The reason that point was raised is not that the speaker is inclined to differ with you, but to bring out this feature, that there may be a hesitancy upon the part of the water companies to allow a ground to their services, due to the fact that the service may be of comparatively small capacity, and it may be at a point where there would be more or less occasion for the water employes to be about, and there might be a hesitancy in granting permission, when granting permission to establish one good ground upon a large water main near a transformer location would accomplish the same results. It seems that a water works man would much prefer extending the privilege of making one good ground than a multiplicity of grounds through all of his varied customers' services.

MR. BURTON MCCOLLOM: In reply to that, the speaker would very strongly urge upon the water people that they do not raise any objection whatever to making as many grounds as the lighting company wishes to make on the pipe system. The more frequently the lighting company can ground its system, the less the possibility of hazard, either to the water company employes or to the public. There is one other point that should have been mentioned, that has a bearing on the case, and that is the question of lightning protection. The only effective way to provide for lightning protection is to permit the lightning to discharge to the ground just as quickly as possible. Lightning is liable to strike the service wires between the transformer and the customer's premises, or it may strike right close to the customer's premises. If there is only one ground, and that at the transformer, the lightning discharge, in order to get to the ground, has to go for some distance on the wire to the ground point. It is well known that a lightning discharge has often a wave front, and having a steep wave front, it tends to take the shortest possible path to the ground because of the inductance of any wires along which it might otherwise travel. In some instances a lightning discharge will jump several feet through the air to the ground rather than run 50 yards along a wire to the point where the wire itself was thoroughly grounded because of the inductance of the wire. Now, if you have only one ground at the transformer, and lightning strikes the wire 50 or a 100 yards away from the transformer, the probability that it will jump from the wire to some grounded structure, like a pipe system in the house, is very great and in

doing so it may go through a wooden partition and the arc is liable to ignite the wood and set fire to the premises, in addition to possible danger of shock to occupants. This danger is practically removed if you ground the secondary at or very near to each customer's premises. Then the lightning discharge can go directly into that individual ground and will not jump across and possibly give a fire or accident hazard.

MR. JOE C. BEARDSLEY: There is a question that perhaps might interest some of the members present, and that is the subject of water meters. Almost all water meters used today have hard rubber working parts, and in at least some of them, the clearance on these meters is very small. The majority of meters used today are made of brass. Now, the clearance in the particular meter the speaker has in mind is $\frac{1}{15}$ of an inch, and a very slight degree of heat will expand that hard rubber disc so that it will stick. Is there any possibility of an electrical contact causing heat to expand the disc to that extent? For instance, supposing you grounded a telephone wire on your water service close to the meter, and that became crossed with a high tension wire that would cause considerable heat there. Would that affect the working parts of the meter?

MR. BURTON MCCOLLOM: How much clearance did you say there is?

MR. JOE C. BEARDSLEY: The particular meter in mind is $\frac{1}{15}$ of an inch, that is between the disc and the walls of the disc chamber. That is, it fits quite as close as a piston does in a cylinder.

MR. BURTON MCCOLLOM: What is the diameter of the disc?

MR. JOE C. BEARDSLEY: It depends on the size of the meter. In an ordinary house service meter it is something over three inches, about three inches and a half.

MR. BURTON MCCOLLOM: Can answer that only from a rough estimate, not from actual knowledge, but it would seem that it would be practically out of the question that there would be enough expansion due to the heat generated by any current that would flow through the pipes and meter to cause it to stick, because it would not be possible to get enough current through there in any case to

generate sufficient heat to raise it above the temperature of boiling water, and that temperature would not be sufficient to expand the hard rubber enough to affect the working parts of the meter.

MR. JOE C. BEARDSLEY: Still the temperature necessary to expand the rubber need not be over 140 or 150°; that is sufficient to cause the disc to stick.

MR. BURTON MCCOLLOM: That may be so. The speaker would not really be able to answer the question definitely at all, except that a pipe with water in it generally has the water running very cool, even if there is considerable current flowing through it, and it is extremely rare that a pipe becomes very warm. What you have in mind is that there is a current that might flow in case of a rather bad short circuit between the high voltage line and the low voltage line.

MR. JOE C. BEARDSLEY: That is it, with the telephone wire grounded on the service.

MR. BURTON MCCOLLOM: On further reflection, there is a possibility that that might be the case. The speaker had in mind a single instance in which a lead service pipe melted off by heavy current flowing in it, and certainly a current of that strength would heat a pipe.

MR. JOE C. BEARDSLEY: The speaker remembers reading some years ago of a fire that was caused in Boston, in one of the suburbs, by the crossing of a telephone wire that was grounded on a water service, with a high voltage wire; or at least they supposed that that was the cause of the fire, and it would seem that it might also cause damage to meters.

MR. BURTON MCCOLLOM: If the ground connection is made on the street side of the service cutoff, probably the heat would not get to the meter to a sufficient extent to cause trouble. Of course, there would be a possibility of some heat conduction along the pipe through the meter, so that one could not positively say it would not happen, even if the connection was made outside of the meter, but in a good many cases the ground is not made far enough out to the street. That is another reason for grounding as near the street as possible; perhaps it is not an important one though.

METHODS OF SENDING SPECIMENS OF WATER[1]

By Jack J. Hinman, Jr.[2]

In order that a water supply may be examined fairly, it is of primary importance that a true sample be submitted to the analyst for examination. Anything which might result in the introduction of foreign material, especially bacteria, may easily result in improper findings which would usually be to the disadvantage of the supply.

The first requisite for the collection of the sample is a properly prepared bottle. Any bottle or jug will not do. It must be chemically clean, and if there is a bacteriological examination to be made, it must be sterile. Any cleaning solution used should be thoroughly removed, since many such solutions are germicidal in character. The sterilization of the bottle should be accomplished by boiling in water, steaming or by the use of dry heat. To attempt to sterilize a bottle by means of chemical disinfectants may lead to erroneous results unless the greatest care is taken to rinse out the last traces of the chemical; in which case the repeated rinsings may defeat the sterilization by introducing contaminating material. The bottle should be closed with a glass stopper, because cork stoppers are difficult to sterilize by the means usually at hand outside of the laboratory, and have the additional disadvantage of yielding various substances to the water from the many cracks and crevices. The use of corncobs, rolled paper and such substances is naturally to be avoided.

Jugs should never be used because the roughness of their interiors is likely to cause adhering materials to be much more difficult to remove. It is also impossible to see whether or not the jug is clean. Supposedly clean new jugs frequently contain straw and other similar substances. Many jugs are glazed by the use of salt which may add to the chlorine content of the water.

[1] Read at the first annual meeting Iowa Section, American Water Works Association, at Iowa City, December 3, 1915.

[2] Senior water bacteriologist and chemist, Laboratories for the State Board of Health, Department of Pathology and Bacteriology State University of Iowa, Iowa City.

It is best in all cases to send to the examining laboratory for the collecting bottles because any such laboratory will be found equipped with suitable apparatus for the cleaning and sterilization of the sample bottles. The laboratory should provide some means of sealing sterile glassware and you should receive the bottle with the seals intact, thus assuring you that they are in condition for use. Having received the sterile bottles the collection of the water must be carefully made. It is easy to set at naught the pains that have been taken to furnish a clean sterile container. It is usually a waste of time and money to entrust the collection of samples of water to an uninstructed workman. The collector should be familiar with the usual precautions to be observed in taking a sample of water, since everyone does not appreciate the ease with which bacteria may be introduced or a measurable quantity of foreign matter added. When chemical tests are made to one part in a hundred or a thousand million in routine examination and bacteria are counted, the ubiquity of bacteria and the great influence of an almost imperceptible amount of dirt must be taken into consideration.

The usual precautions are as follows:

1. Allow the water to flow until the water which has stood in the pipe has wasted, because since it has stood in a more or less warm place for some time, the bacteria have probably increased in number and chemical changes have gone on. If the sample is taken from a street hydrant or similar source an accumulation of iron will need to be flushed out.

2. Remove the cover from the top of the bottle, holding it in such a way that the inside of it is not soiled by contact with the hand or any other object. Open the bottle while the water is running; fill it nearly full, rinse, refill; rinse the ground part of the stopper and insert the stopper. Take great care throughout that the stopper, the inside of the neck of the bottle and the water collected are kept from contact with the outside of the faucet, the hand, a cloth or any other object.

3. Protect the top of the bottle from dust and other contaminating substances by replacing its cover of tin-foil or cloth. When a sample of water has been properly collected in a proper sort of container, the manner of shipment to the laboratory must be considered. Chemical and bacterial changes take place with varying rapidity, depending on the character of the water, the temperature at which it is kept, the exposure to light, etc. To secure the best results,

that is, to deliver it to the laboratory in as nearly unchanged condition as possible, the time consumed in transit should be short and the temperature of the water should be kept low. The low temperature retards the multiplication of bacteria and minimizes the chemical change.

For some time the water laboratory of the Iowa State Board of Health has been using 1 gallon glass stoppered bottles for the collection of water samples. The bottle is slipped into a felt-lined case, open at the top; it fits tightly into the case and the felt lining serves to protect the bottle from breakage and to protect its contents to a certain extent from extremes of temperature. The case is left open at the top so that the expressmen can see what they are handling and use suitable caution. Concerning the breakage of bottles in shipment it is only fair to state that our breakage has been less than 1 per cent.

The bottle is prepared for use by cleaning with a strong solution of potassium bichromate and sulphuric acid, as directed in the *Standard Methods of Water Analysis*, and then sterilized by steam. A sterilized muslin cloth is tied over the top by a stout cord, the ends of which are then sealed upon the top of the stopper by an official wax seal. Owing to the fact that the bottles are necessarily of a rather thick glass, they are often cracked during sterilization. This occasions most of our breakage of bottles, which is a factor of consequence, since the bottles cost about 80 cents a piece.

The gallon-bottle outfit was adopted when the laboratory was first established because the investigations of Whipple and others (as well as some work in our own laboratory) had shown that chemical and bacterial changes are less in a large bottle of water than in a small bottle of the same water, given the same temperature conditions.

A long series of experiments carried out during the summer months has shown us that, while we are able to get bacteriological results of considerable diagnostic value from samples so collected, the bacterial counts are not rigidly exact enough to be of great value in checking up the operation of a water works filter plant. For this purpose, we have used a smaller bottle packed in a case which may be iced. Although the bacterial examination is the chief requirement in such cases, it may often be that a chemical examination is required as well. To collect the large sample as well as a small one is inconvenient and the extra expressage is not an inconsiderable item.

For field work the large bottle is unhandy. It is difficult to collect a sample from streams or ponds especially if they be shallow. Although the bottle contains 3700 to 3800 cc. only about 800 cc. of water are used in the routine procedure. The excess is of value only as it helps to retard the changes in the sample.

Penniman and Enslow of the Maryland State Board of Health have recently reported on their successful use of a 1 pint sample for chemical analysis. This container was not intended to furnish a bacteriological sample as well. Since only a few more cubic centimeters are required for the ordinary bacterial counts and fermentation tubes, it occurred to us that we might use a similar sized bottle and send the sample packed in ice in a case slightly smaller than the old bacteriological case which we had been using. The ice packing should serve to retard chemical and bacterial changes even more than the use of such a container as our old one. Under such conditions it is necessary to collect only a small extra quantity of water to allow for accidents, and for rinsing of the measuring vessels.

By reducing the quantity of water used in the ammonia determinations from 500 cc. to 100 cc. the amount of water collected may be reduced to 500 cc. and yet leave a margin of 100 cc. to provide for an emergency. Penniman and Enslow claimed to be able to do this without reducing the accuracy of the method. Our preliminary work has verified their results in a general way, although we find that it is more difficult to read low ammonias. This is due to the fact that our first tube of 25 cc. of distillate represents a concentration of most of the ammonia in an amount of water equal to one-fourth the volume of water used in the determination, while in the old method, we have a concentration to one-tenth the volume.

Penniman and Enslow used short shell vials for Nessler jars which they graduated themselves. We have used homemade Nessler jars blown out of $\frac{1}{2}$-inch glass tube. These provide a longer column of liquid. We have used small Kjeldahl flasks instead of small retorts such as were used by Penniman and Enslow. Our routine chemical examination includes nitrogen as free and albuminoid ammonias, nitrites and nitrates and chlorine. It is not necessary to reduce the quantities of water taken for the other tests.

The new case is in the form of a box about $8\frac{1}{2}$ by $8\frac{1}{2}$ by 11 inches furnished with hinged cover, hasp and handle. The inside dimensions are 7 by 7 by $9\frac{1}{2}$ inches. It is lined with galvanized iron. The bottle is enclosed in a cylindrical galvanized box 4 inches in

diameter and 9 inches high which on account of its dimensions can not fall over in the box and fill with water produced from the melting ice. A lead seal securing the hasp of the box insures the sterility of the bottle.

It requires about 6 pounds of ice to fill the container properly. A few ounces of excelsior or saw dust should be added with the ice so that the bottle may carry well and the ice be kept from rapid melting. Excelsior is cleaner to handle than sawdust but it does not protect the ice as well.

Most of our samples reach us about twenty-four hours after collection. Our experiments at the laboratory, using the very inferior natural ice which has been available, show that this container will keep the temperature of the sample for a period of forty-eight hours several degrees below the surrounding temperature even in hot weather.

The box, metal fittings and bottle complete cost in the neighborhood of $1.75 or $2

THE AIR LIFT[1]

By Arthur H. Ford[2]

Since the cost of pumping is one of the principal items in the cost of supplying water to the residents of a municipality, every water works manager is interested in discussions regarding the relative costs of pumping by different methods. Of late years, the air lift, as a means for raising water from deep wells, has become of such great importance that the writer deems a short discussion of the subject worthy of your attention.

Though air lifts have been used for the past fifty years for pumping water from wells of all depths, the theory of their operation has defied mathematical analysis; with the result that their design is almost wholly dependent on the use of empirical formulae. This has led to the improper design and operation of many lifts, to the detriment of their efficiency.

In general, an air lift consists of a water pipe extending a considerable distance below the water level in the well, where it is joined to an air pipe by means of a foot piece. The air pipe is connected to a compressed air receiver which is supplied with air by a compressor. It is thus seen that there are no moving parts in the well, which makes this type of pump especially desirable for use in crooked or deep wells, where the cost of repairs on pump rods and cylinders is large. The lack of moving parts in the well also increases the reliability, which is a great advantage in those cases where one well only is depended on for the water supply; it also makes it possible to handle water containing so much grit that reciprocating pumps will not answer, because of the excessive wear of the cylinders. Air lifts can pump water faster than any other type of pump, and are therefore frequently used for the purpose of testing new wells. The rapid rate of pumping water is such a desirable feature that this alone may lead to the use of an air lift in preference to a pump of some other form.

[1] Read at the first annual meeting Iowa Section, American Water Works Association, at Iowa City, December 3, 1915.

[2] Professor and Head of the Department of Electrical Engineering, State University of Iowa.

A picture of a working model of the simplest form of air lift is shown in figure 1. The outer tube (*W*) represents the well; connected to the catchment basin (*B*) by means of the siphon (*S*) which

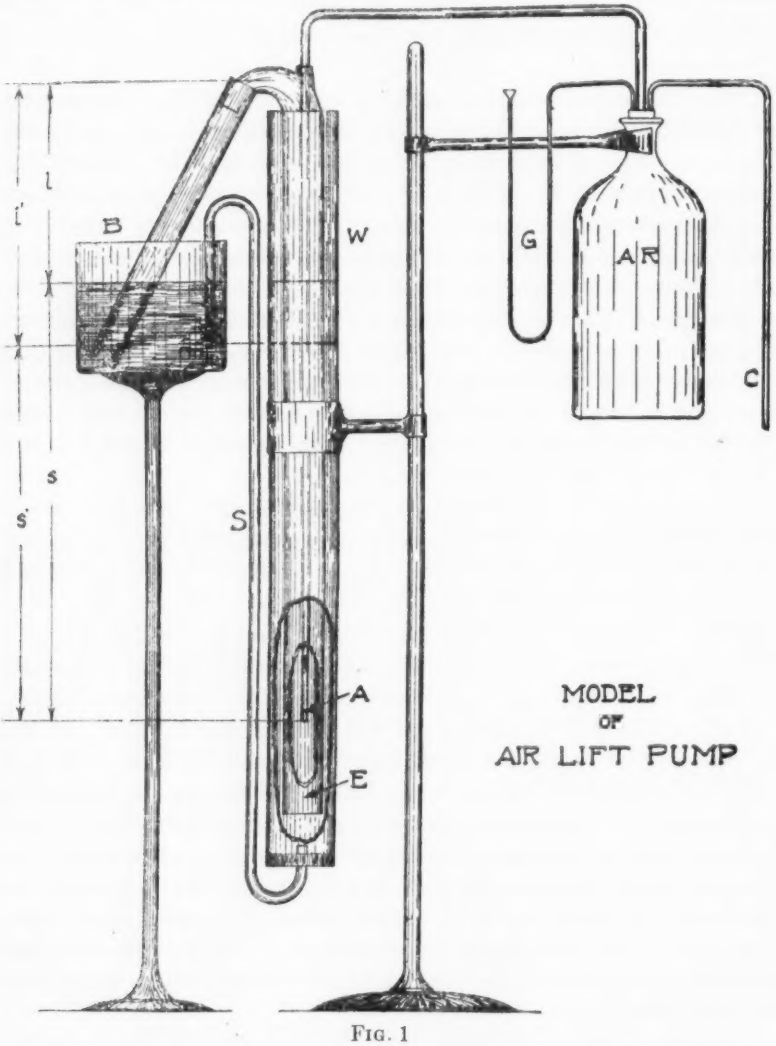

FIG. 1

represents the water passages in the rock. Inside the well is suspended the eduction tube (*E*) having the air tube (*A*) suspended in it, but not reaching quite to its bottom. The air tube is connected

to the air receiver (AR) which is supplied with a pressure gauge (G) and a connection (C) to the air compressor (not shown).

When the compressor is started, the pressure in the air receiver gradually increases and the water is forced out of the air pipe until it is entirely empty, at which time the air pressure is at a maximum. The air now bubbles out of the end of the air pipe into the eduction pipe, which causes the level of the water in this pipe to rise an amount proportional to the volume of the air in the bubbles. As long as this does not bring the top of the column of air and water above the discharge opening in the eduction pipe, no water will be pumped and the air will merely bubble through the column of water. This condition obtains when the quantity of air supplied is insufficient to operate the lift.

The supply of a larger quantity of air will cause a larger proportion of the mixture in the eduction pipe to consist of air, with the result that the column will be higher, and when the air supply is sufficient the top will be above the discharge opening and the pump will begin to operate. The manner of operation will depend on the relation of the rate at which air is supplied to the area of the eduction pipe. When the rate of air flow is small, the air bubbles will be small in comparison with the size of the eduction pipe and the flow will be steady. Such a flow can be attained only when the pumping head (l) is small in comparison with the submergence (s) of the air pipe.

When the rate of air supply is increased, the size of the air bubbles increases until they entirely fill the eduction pipe and form air pistons enclosing slugs of water between them. The flow now becomes pulsating; discharges of water and air alternating. Every time that a slug of water is thrown out, the pressure at the lower end of the air pipe is slightly reduced and a quantity of air is emitted. This lifts the column of air and water in the eduction pipe, and at the same time stops the flow of water into the lower end; with the result that the level of the water in the well rises, increasing the water pressure at the end of the air pipe. As soon as the water pressure exceeds the air pressure the air flow stops until the pressure is again reduced by a slug of water being thrown out of the eduction pipe.

The maximum air pressure required to start a lift operating is equal to 2.31 times the submergence (s) of the air pipe, in feet. As soon as the lift begins to operate, the pressure is reduced, because of the drawing down of the water in the well, thus reducing the sub-

mergence to s', and increasing the head to l'. (See fig. 1.) This lowering of the water level may be considerable and is the determining factor in fixing the economical rate of pumping.

A number of the factors which enter into the efficiency of an air lift must of necessity be determined by experiment on the particular well in question; but some of them admit of generally applicable determinations being made. Among these is the best form of foot piece, as the connection between the air pipe and the eduction pipe is called. There are a number of forms of foot pieces on the market, for some of which extravagant claims of efficiency are made; but as wide variations in the efficiency are due to slight changes in the proportions of other parts of the system or the method of operation,

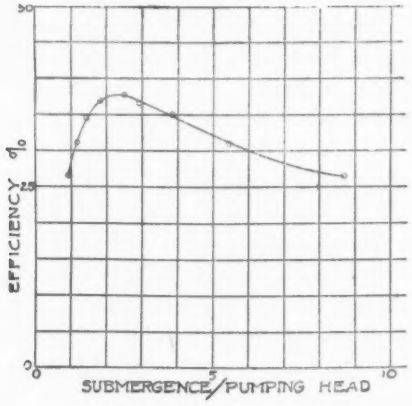

FIG. 2

such claims are to be looked on askance, unless they are backed up by adequate guarantees. Tests have shown that the effect of a change in foot piece may be to increase the efficiency as much as 50 per cent, when the head is high, with a much smaller increase when the head is low.[3]

The efficiency of even a well designed air lift is low; varying from 20 per cent for a lift of 600 feet, to 45 per cent for a lift of 50 feet; and is greatly influenced by the ratio of the submergence of the air pipe to the lift; the best ratio being about 2. This is clearly shown by a test of a well at Hattiesburg, Mississippi.[4] In this test, the speed of the air compressor was adjusted so as to keep the rate

[3] *Pumping by Compressed Air.* E. M. Ivens, page 146.

[4] Ibid., page 112.

of flow of water constant, while the length of the air pipe was varied. The data are given in the following table and shown in figure 2.

Total depth of well	453.5 feet
Inside diameter of casing	9⅝ inches
Inside diameter of air pipe	2½ inches
Inside diameter of eduction pipe	9⅝ inches
Static lift (l)	4.0 feet

Effect of submergence on efficiency pumping head

SUBMERGENCE	EFFICIENCY	SUBMERGENCE	EFFICIENCY
	per cent		*per cent*
8.70	26.5	1.86	36.8
5.46	31.0	1.45	34.5
3.86	35.0	1.19	31.0
2.91	36.6	0.96	26.5
2.25	37.7		

Flow about 1100 gallons per minute; pumping head about 37 feet.

These results show that the maximum efficiency is secured when the submergence is 2.5 times the lift, and that the efficiency falls off more rapidly for a reduction in the submergence than for an increase. It is a good plan therefore to have the submergence more than that calculated for the best efficiency rather than less. This allows for the usual occurrence, viz., that the pumping lift increases as more wells are sunk or during a dry season. Previous to this test the length of the air pipe in this well had been varied with a view to finding out the best flow at which to operate the well. The important data are given below and plotted in figure 3.

LENGTH OF AIR PIPE	FLOW	PUMPING HEAD	EFFICIENCY	DUTY
feet	*gal. per min.*	*feet*	*per cent*	*gal. per hp. hr.*
224	1495	47.5	32.6	1630
208	1459	45.8	31.5	1640
184	1419	44.3	31.1	1670
162	1359	39.4	30.0	1790
142	1299	37.7	30.6	1920
124	1219	37.5	32.8	2070
105	1106	37.1	36.7	2340
86	1008	32.5	33.4	2450
79	904	29.3	31.3	2530
67	802	26.0	30.5	2750
43	690	21.2	29.8	3240

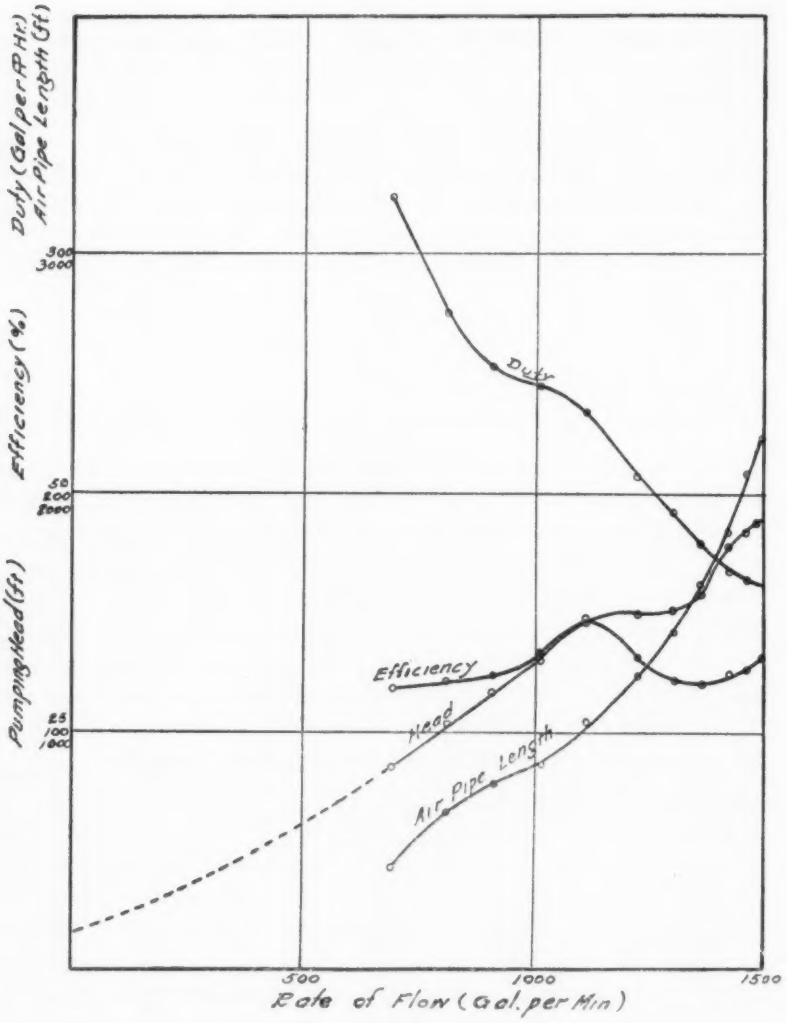
Duty (Gal per HP Hr)
Air Pipe Length (Ft)
300
3000
Efficiency (%)
50
200
2000
Pumping Head (Ft)
25
100
1000
Duty
Efficiency
Head
Air Pipe Length
500
1000
1500
Rate of Flow (Gal. per Min)

FIG. 3

The air supply was apparently adjusted so as to get the best efficiency for each submergence.

This test shows an anomalous variation of the relation of pumping head to rate of flow; which is probably due to the coming into action of a second water bearing stratum, there being two cut by the well, when the level of the water had dropped 33 feet on account of the operation of the lift.

The writer believes that pump duty, water pumped per unit of energy supply, should be made the criterion of operation rather than mechanical efficiency. He has therefore calculated the last column.

This shows that the duty of the lift increases as the rate of pumping is decreased; which is due primarily to the decrease in the pumping head. The variation will be small for a free flowing well or one in which the drop due to pumping is small in comparison with the pumping head. This dictates that the well should be pumped at the minimum rate at which the desired quantity of water will be furnished.

When the well under discussion is operated at a flow of 1106 gallons per minute, at which flow the maximum efficiency was obtained, the pump duty was 2340 gallons per horse power hour; while if the pumping rate had been reduced to 690 gallons per minute the duty would have been 3240 gallons per horse power hour—an increase of 38 per cent. This would reduce the pumping expense 28 per cent.

The present status of the air lift is such that it can be considered as a thoroughly reliable piece of apparatus; but one should not be installed without the advice of an engineer who has made a special study of the subject, and he should be given opportunity to make trials with various lengths of air pipe and various speeds of compressor operation, after the lift has been installed; so as to find the conditions for best operation.

THE RELATIONSHIP OF THE EPIDEMIOLOGIST TO WATER WORKS MEN[1]

By Mark F. Boyd, M.D.[2]

We may define epidemiology as a study of the factors influencing the transmission of the communicable diseases. Its scope includes the microörganisms causing disease, their means of transmission from one individual to another and of the opportunities that facilitate or hinder transmission. This knowledge may be effectively applied in disease prevention and eradication.

Water works men are chiefly interested in the part that public water supplies may play in the transfer of infection. The microorganisms causing typhoid fever, asiatic cholera and dysentery, and perhaps some other communicable diseases, may be transmitted by infected water supplies, but to us, as dwellers in the temperate belt, typhoid fever is the most important, and is from a practical standpoint the only disease we encounter which may be transmitted through water.

Before considering the characteristics of water-borne typhoid fever, it might be well to state some fundamental facts regarding the origin and spread of the disease. Typhoid fever is an infectious disease caused by the bacillus typhosus. This organism never develops spontaneously, but always has its origin from the discharges of some previous case of typhoid fever or a carrier of the organism, who is usually a person that has recovered from the disease, and in whose body certain poorly understood biological relationships exist that permit him to continue to harbor the typhoid bacillus and discharge it intermittently in his feces and urine. From such sources of infection the typhoid bacillus may be transferred to susceptible persons through the routes of infection of contact, water, milk, ice cream, uncooked and cold foods, flies and some other relatively insignificant routes of infection. An inquiry into the prevalence of

[1] Read at the first annual meeting Iowa Section, American Water Works Association, at Iowa City, December 3, 1915.

[2] Epidemiologist, State Board of Health Laboratories, State University of Iowa.

typhoid fever, therefore, has to consider the opportunities which have existed for the infection of these substances, consumed by the patients at the probable time of infection.

Public water supplies may be either continuously or intermittently infected with the typhoid bacillus. The source of supply may become contaminated from the sewage of other towns, from the sewage of the same city, from the waste of individual houses, institutions or factories, from privies situated directly on or over the banks of the source of supply, or excrement which has been deposited on the ground being washed into a water course by rain or by seepage; or the supply may become infected through the temporary admission into mains of water from a contaminated source at the time of some accident or emergency. Where infection is continuous the source of supply is heavily polluted with sewage the year round. Its effect is manifest by a very high typhoid fever case rate and death rate extending throughout the year; in other words as an epidemic of long duration. Where the infection is intermittent or temporary the disease outbreak appears as an explosive epidemic from two to four weeks after the temporary contamination occurred. Moreover, epidemics due to temporary infection present certain distinctive characteristics. In a temporary infection of a water supply the infection is generally rather dilute, unless a grossly polluted source of supply has been temporarily substituted. The typhoid bacillus does not find water a favorable medium for its continued growth and multiplication and gradually diminishes in numbers until finally extinct. This characteristic is well known and used in the purification of water by storage. The decrease in the numbers of the typhoid bacillus takes place more rapidly in the summer months than in the winter. Most large water-borne epidemics have occurred in northern cities, both in this country and Europe and nearly always occur in the spring, fall or winter when the water is cold. The number of cases developing daily shows a rapid rise, soon reaches a maximum and rapidly declines; in other words the epidemic is explosive. The contamination of the water is usually nearby, and the transfer of virulent organisms is fairly rapid.

In the investigation of a typhoid epidemic where the evidence collected indicates infection from a contaminated water supply, we generally find something like the following: All or nearly all cases will give a history of the use of the suspected water at about the approximate time of infection, for drinking, or have eaten raw

vegetables washed in it, or used it in washing the mouth. In public supplies the infection will be distributed uniformly through the population regardless of age and sex and largely coincide with the limits of the water supply. Cases living outside the limits of the supply will usually be found to have used the water at school or place of business or elsewhere. When private supplies are infected the distribution of cases is generally localized and confined among those of a particular nationality, age group, sex or occupation, etc. These are but a few of the characteristics of a water-borne outbreak of disease.

While water-borne typhoid is of very common occurrence, it is not the sole or chief cause of typhoid and is playing a rapidly diminishing rôle in the spread of the typhoid bacillus. The great water-borne epidemics have ove shadowed other means of infection. The larger part of the typhoid fever prevalent is not water-borne. In 1908 Whipple estimated that 35 per cent of the cases were contracted from water, and at present the percentage must be much less. Typhoid fever may be excessively prevalent, even epidemic in a city having a water supply of a good sanitary character.

Every water works superintendent should keep constantly posted on the current prevalence of typhoid fever in the city or town he serves, and at the first manifestation of an undue increase in the disease should insist that the local board of health institute an epidemiological investigation of the disease. Furthermore, every public water supply, no matter what its sanitary quality, should be equipped with either a hypochlorite or liquid chlorine sterilization plant, for continuous or emergency use. An installation for the use of hypochlorite will probably be found the most economical to install and can be constructed by the water works force. Then at any time, should emergency compel the use of water of doubtful source, the health of the community can be safeguarded by sterilization of the water.

NOTES ON FIRE PROTECTION[1]

By T. N. Hooper[2]

In the year 1914 there were 406 actual fires in the city of Davenport. In the year 1913 there were 370, so that it is safe to say there is an average of one fire per day. It is the business of the water department to be prepared to drown out any fire at any point in the city at any moment and without delay. It is therefore plain that a proper water works system must be prepared and equipped with all necessary intakes, pumping machinery, mains and appurtenances required for fire protection. Few outside persons realize the large part of the total investment in a well designed water works that is required solely to meet the fire demand.

Just a few words in regard to the design and operation of a water works system with especial reference to fire protection. Water works installations are not built as a whole; they are a matter of growth and they grow with the town. When the first mains are laid out, it is not known where the principal hazards will grow up in later years so that oftentimes mains are laid that are too small. Later these have to be reinforced with larger pipes. Extensions are continually being carried out in the outlying districts, radiating like the fingers of the hand. These extensions need tying together and must be gradually brought into a system. One of the greatest difficulties is to maintain a proper percentage of large mains. Each year small mains are laid for extensions and under ordinary circumstances the laying of larger mains, as feeders, is deferred.

In Davenport there are today 98.14 miles of mains. Of this 23 per cent are of sizes 12 inches and over; only 3.6 per cent are under 6 inches in size. The present practice is to lay no mains smaller than 8-inch diameter in important districts and no mains are laid at all under 6-inch diameter. In 1909 there were 5 miles of 4-inch pipe in Davenport—today there are 3½ miles. Some 4-inch

[1] Read at the first annual meeting Iowa Section, American Water Works Association, at Iowa City, December 3, 1915.

[2] Vice-President, Davenport Water Company, Davenport, Iowa.

is taken up every year and it is proposed to remove it all. Large mains are not necessary to supply consumers with water, but they must be there to furnish the proper quantities for fire extinction at any time, even if they are not called upon to do so for many years in succession. When small mains are crossed by mains of larger size, it is the practice to remove fire hydrant on intersection where the cross occurs and to set the hydrant on the larger size main. In this way, after a time, very few hydrants are found on small mains in important districts.

The commercial district of Davenport extends from Rock Island Street to Scott Street and from Front Street to Fourth Street, embracing eighteen city blocks. These blocks are approximately 400 feet square. Through this district there are three 16-inch mains laid parallel and one 8-inch main. The four mains mentioned are cross connected by two 16-inch mains; two 12-inch mains; two 8-inch mains, and one main partly 8-inch and partly 6-inch. Throughout this district there are but two blocks having 6-inch pipe and but one block on which there is no pipe. Feeding this gridiron there are three mains from the pumping station $1\frac{1}{2}$ miles distant, one 14-inch, one 16-inch and one 24-inch. In addition to this there is a 16-inch main which may be used to supply water from the pumping station at elevated storage reservoir 179 feet above datum and 1 mile away. This reservoir pumping station supplies high level residence district by direct pumping, taking suction from the storage reservoir. When there is a large fire on lower level, the changing of two gate valves allows pumping down hill through the supply main, giving a pressure of 100 pounds in the commercial district when carrying 40 pounds at the station.

There is not space in a short paper to describe the principal features of an ideal plant, but it is believed that the principal fault in the present practice in many cities is that mains are laid that are too small and these small mains are not thoroughly connected. The advantage in having mains of ample size is that the excessive pressures oftentimes carried at pumping stations are avoided. Also, when large quantities are required at some point in the distribution system they can be supplied from the pumping station without creating high velocities in any mains.

It has always been the practice in Davenport to place a gate valve on the branch supplying each hydrant. It is never necessary to shut off mains in order to make repairs to fire hydrants. Another

practice which has proved to be wise and economical is frequent inspection of fire hydrants in cold weather. Every fire hydrant, and there are 924 altogether, is inspected at least once a week in cold weather, and in very severe weather twice a week. It is known at all times that the caps are free and can easily be taken off by the fire department. A pump with suction hose is used to prove that there is no water in the barrel of the hydrant. Theoretically, every hydrant is tight as to its main valve and no one is supposed to use it in cold weather. Practically, main valves are not always tight and oftentimes there is ground water which enters the hydrant barrel through waste outlet, and again, unauthorized persons will open hydrants occasionally. It is better to know of these things than to discover them during the time of a fire. It is the experience of all water works operators that the main difficulty in keeping fire hydrants ready for service is the failure to confine the use of hydrants to the experienced firemen and water works employees.

Another precaution observed in our plant is the practice of sending men to every fire whether night or day and at second alarm fires, everyone is called who can be of any assistance. The superintendent is found at the main pumping station where there are duplicate telephones which may be used to control pumping in the other pumping station. The assistant superintendent is always on duty at the fire, and other men, with automobiles and tools, are prepared to answer any calls instantly. Each man has his place; each man knows where the others may be found.

During the past two years all hydrants set have standard $4\frac{1}{2}$-inch steamer nozzles as well as the usual two $2\frac{1}{2}$ inch nozzles. Davenport has no steamer or pumping machine, and may not have for many years, but should the time come when it is necessary or desirable to use fire department pumping apparatus, the hydrants will be prepared for it. No hydrants having less than 7-inch barrels, 5-inch valve openings and 6-inch connection to the mains have been set for several years. There is no hydrant having connection to the main less than 5 inches diameter or having barrel less than $5\frac{3}{4}$ inches.

EXPERIMENTS IN WATER SOFTENING WITH A ZEOLITE-LIKE SUBSTANCE[1]

By Robert N. Kinnaird[2]

The application of the chemical exchange properties of zeolites to the art of water softening indicates an important step in the evolution of the art. The peculiar ability of zeolites to exchange their alkaline bases has been known for a number of years. Dr. Robert Gans of the Royal Prussian Geological Institute has been the foremost investigator of this group of minerals, and is probably the first to conceive of their applicability to water purification. Dr. Gans and others have measured the exchange capacity of a large variety of natural zeolites, and concluded that the natural deposits were either too rare or too greatly associated with impurities to be of commercial value in themselves. He therefore sought to develop a synthetic product having as large an exchange capacity as possible. His product is beginning to be fairly well known in this country and is coming into extensive commercial use abroad.

You are probably acquainted with the general nature of the process. The synthetic product, in chemical composition, is a hydrous aluminum silicate in combination with sodium. A hard water containing calcium and magnesium salts in contact with this material exchanges its calcium and magnesium ions for the sodium ions in the silicate, the result being that the medium is transformed to a calcium silicate, and the salts carried by the water become sodium salts in combination with the original acid radicals. After the silicate has absorbed its capacity of lime and magnesia, it is restored to its original sodium condition by forcing the action in the opposite direction through the agency of a solution of salt or sodium chloride. Under such conditions as are favorable this artificial product is the basis of an ideal process. Salt is cheap. The chemical application is automatic in so far that fluctuating hardness is self-adjusting.

[1] Read before the Iowa Section of the American Water Works Association, Iowa City, Iowa, December 3, 1915.

[2] Chief Engineer, Des Moines Water Company.

No precipitation of insoluble salts is involved, consequently there is no insoluble sludge of which to dispose. Sedimentation and filtration are eliminated.

The natural substance, which the writer has been investigating, is a hydrous aluminum silicate in combination with calcium, which is capable of exchange for sodium in the raw state at a high rate and to at least as high a capacity as the synthetic product. The writer has succeeded in evolving a method of measurement of the rates of exchange in both directions of the reaction with considerable reliability and accuracy.

Des Moines city water which has a total carbonate and sulphate hardness of over 300 parts per million has been softened in experimental filters. In the laboratory of Dr. Edward Bartow of the Illinois State Water Survey these Des Moines experiments have been duplicated with the University of Illinois water having a total carbonate hardness of 300 parts per million.

With a filter layer 2 feet in thickness, rates of filtration of 2 gallons per minute per square foot and upwards have been obtained with water of 300 parts per million hardness. This is equal to the rapid sand filtration rates and suggests the substitution of this natural medium either in gravity or pressure filters for municipal use. The requirements for containers and drainage and washing systems would not be unlike the arrangement for rapid sand filtration. More idle time would be involved in the regenerating process than is at present consumed in washing the filters which would increase somewhat the bulk of the equipment. The cost per unit capacity would therefore be somewhat more than the cost of rapid sand filters. The other items of expense would be in the cost of the medium as compared with sand, its life and the cost of salt for regeneration. It is not unlikely that the medium can be produced very cheaply, as compared with a synthetic product. The material with which the writer has experimented requires some refining and hardening to give it mechanical form. The process is not involved and if handled in large quantities can be made to meet a heavy demand at an easily practicable figure.

Present information indicates that 4 pounds of salt can be counted upon to completely convert 1 pound of equivalent calcium carbonate to sodium carbonate, and the writer feels justified in saying that the indications are that this can be reduced. Assuming a ratio of 4 to 1, and 300 parts per million hardness, 10 pounds of salt would be

required to treat 1000 gallons of water. Salt is marketed in carload lots at $3 and upwards per ton. Assuming $5 per ton, the chemical cost would be 2½ cents per 1000 gallons which is easily competitiv with lime and soda.

The two processes, however, are not strictly comparable. The zeolite process gives a completely softened water without reducing the total solids. The lime process reduces the hardness by the amount of bicarbonates, while the soda process is only useful in that it converts calcium and magnesium sulphates to the sodium sulphates, which is exactly the same chemical substitution as is made by the zeolite. Either alone or in combination with lime, the zeolite process will be a most valuable finishing process. For waters harder or softer than 300 parts per million the cost figures would vary about in proportion to the hardness. Complete softening would probably be neither necessary nor desirable for municipal use, which would reduce the cost proportionately. For harder waters, the depth of the medium layer could be somewhat increased, sufficient probably to maintain rates of flow nearer the usual rates, without increasing the equipment except as to depth of the containers.

THE SECTIONS

NEW YORK

The second 1915–1916 meeting of the New York Section was held at the Manhattan Hotel, New York City, December 15, 1915. Luncheon was served at 1 p.m., ninety members and guests being present. The topic for discussion was "Filter Troubles," and papers were read by Mr. G. R. Spaulding, "Effect of Solutions of Filter Alum on Brass Pipe and Fittings;" Mr. Albert Tolson and Mr. S. M. Van Loan "Filter Operation;" Mr. Frank E. Hale "Iron Removal by Rapid Sand Filtration;" Mr. G. E. Willcomb, "Resanding Problems at Albany;" Mr. F. W. Green, "Situation at Little Falls, New Jersey."

The third meeting was held at Manhattan Hotel, New York, February 16, 1916. After the luncheon Mr. Nicholas S. Hill Jr., President of the American Water Works Association addressed the meeting, urging greater activity by the members of the section in securing new members for the Association. The term of office of Director Mr. J. Waldo Smith having ended with this meeting, Mr. William W. Brush, Deputy Chief Engineer, Department of Water Supply, Gas and Electricity, New York City, was elected to fill the vacancy. The following papers, illustrated by lantern slides, were then presented: "City Tunnel of the Catskill Aqueduct" by Mr. Walter E. Spear; "The Determination of the Value of Fire Protection Offered by the Queens County Water Company" by Mr. Joseph Goodman; "Improvement of the Water Supply of St. Johns, Newfoundland," by Mr. Francis F. Longley.

4 *State Section*

The organization meeting was held at the Bellevue-Stratford Hotel, Philadelphia, January 18, 1916. A constitution was adopted to be submitted to the Executive Committee of the American Water Works Association. Officers were elected as follows: President, Mr. Carleton E. Davis, Chief Engineer, Philadelphia Water Department; Vice Presidents, Mr. E. M. Hoopes, Superintendent

Wilmington (Delaware) Water Department, Mr. A. M. Quick, Consulting Engineer, Baltimore, Md., and Mr. L. Van Gilder, Consulting Engineer, Atlantic City, N. J.; Secretary-Treasurer Mr. C. R. Wood, Assistant Treasurer Millville Water Company, 400 Chestnut St., Philadelphia, Pa.; Executive Committee, Mr. J. W. Ledoux, Chief Engineer, American Pipe and Construction Company, Mr. N. E. Bartlett, Director, Natrona Water Company, Mr. W. H. Boardman, Consulting Engineer, Philadelphia, Mr. John C. Trautwine, Jr., Consulting Engineer, Philadelphia, Mr. H. D. Brown, President Williamsport (Pennsylvania) Water Company).

Mr. E. W. Cattell and Mr. Nicholas S. Hill Jr., addressed the meeting. Mr. Hill's talk was on the effect of the Sections on the American Water Works Association. A letter from Mr. George G. Earl, past president of the Association, was read. Mr. James T. B. Bowles read a paper on "Tropical Water Supplies, With Special Reference to The Canal Zone and Vera Cruz, Mexico." Mr. John C. Trautwine delivered an address on "Boundaries," advocating watershed subdivisions of the country, rather than politically, or by straight lines. Mr. John D. Kilpatrick spoke on "preparedness;" his speech failed to pass the Censor, though it afforded the members present much joy.

ILLINOIS

The third meeting of the Illinois Section was held jointly with the Illinois Society of Engineers and Surveyors, at the University of Illinois, Urbana, January 25–27, 1916. The first day of the meeting was "Water Works Day," and was devoted to papers, and discussions on water works subjects, by members of the section.

On the evening of January 26 the annual dinner of the two organizations was held at the Beardsley Hotel. An illustrated lecture entitled "Engineering Features of the United States Reclamation Service" was given by Prof. F. H. Newell of the University of Illinois, formerly Director of the Reclamation Service.

President of the Section, Mr. W. J. Spaulding delivered an address at the opening of the section meeting. The following papers were then read: "Bacteria in Deep Wells," F. W. Tanner; "Water Supply on Lake Vessels (illustrated), H. P. Letton; "Typhoid Fever Epidemic Resulting from the Use of a Polluted Water Supply at Old Salem Chautauqua," H. F. Ferguson; "Further Develop-

ment of Iron Removal Plant and Storage," F. C. Amsbary; "Bubbly Creek Water Softening," C. A. Jennings; "Successful Water Softening and What It Costs Hinsdale," C. B. Williams; "Calcium Hypochlorite and the War," W. F. Monfort; "Operating Results at New Filtration Plant, Quincy," W. R. Gelston; "Flow of Water Through Submerged Short Pipe Having Mouthpieces," F. B. Seeley; "Novel Details in Filter Construction at Alton," Paul Hansen; "Science and the Divining Rod," H. E. Babbitt; "Notes on Earth Dam Construction," G. C. Habermeyer; "Cost of Producing Alum," C. P. Hoover; "The Use of Oil Engines for Pumping," C. R. Knowles.

A number of manufacturers and supply firms made exhibits at the joint meeting.

An invitation was extended by the city of Molin, Illinois, to hold the next meeting in that city, and the invitation was accepted, it being understood that the Iowa Section would hold their meeting at Davenport, across the river, at about the same time, so that the two sections could combine their work.

The following officers were elected for the ensuing year: Chairman, Paul Hansen, Engineer State Water Survey, Urbana; Vice-Chairman, E. MacDonald, Superintendent Water and Light Company, Lincoln; Treasurer, H. E. Keeler, President Rogers Park Water Company, Chicago; Trustee: W. E. Lautz, Manager Pekin Water Company, Pekin. Prof. Edward Bartow was reelected Secretary.

The Trustees will consist of the above named and W. W. DeBerard, Western Editor, *Engineering Record*, Chicago, and F. C. Amsbary, Manager Champagne and Urbana Water Company.

COMMITTEES

Mr. Norman F. S. Russell, 1421 Chestnut Street, Philadelphia, has been appointed a member of the Committee on Revision of Standard Specifications for Cast Iron Pipe and Specials, in addition to the members of this committee already published.

Mr. Charles R. Wood, Assistant Treasurer Millville, New Jersey, Water Company has been added to the Committee of Standard Specifications for Valves and Hydrants.